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ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

Report 1168

SHORAN PHOTOGRAMMETRIC MAPPING INSTRUCTIONS

Project 8-35-05-001

15 May 1950

Submitted to

THE CHIEF OF ENGINEERS, U. S. Army

FOR TECHNICAL INFORMATION

by

The Commanding Officer
Engineer Research and Development Laboratories

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CONTENTS

FOREWORD

This report is designed to provide a set of tentative operating instructions for use by Corps of Engineers personnel who may be required to employ Shoran-controlled photography in fulfilling current mapping assignments. The wording and layout have been written in the general form of a training manual so as to facilitate its later publication. The present volume is complete and therefore supersedes ERDL Report 1055, Tentative Operating Instructions for Shoran Photogrammetric Mapping, which was designed for the same purpose but which contained only the first four chapters. Report 1055 should now be destroyed in accordance with paragraph 33, AR 380-5.

The Shoran project was authorized by a 1st indorsement from the Chief of Engineers to the Engineer Research and Development Laboratories (Engineer Board), dated 18 October 1946, subject: Transmittal of Engineer Board Report No. 987, Second Interim Report, Application of Shoran to Mapping (Work Order DMP 3409, MPS 673).

This material has been coordinated with the U. S. Air Force, the Army Map Service, and the Engineer School, and has been informally reviewed by personnel of the U. S. Coast and Geodetic Survey. All information appears to be as nearly correct as can be determined at this stage of the development of Shoran equipment and methods. However, should any errors, omissions, or needed revisions be noted during the use of these instructions, it is requested that comments be furnished to the Engineer Research and Development Laboratories so that necessary changes can be disseminated to all concerned.

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CHAPTER I

GENERAL

SHORAN PHOTOGRAMMETRIC MAPPING INSTRUCTIONS

CHAPTER I

GENERAL

1. Subject and Purpose. This set of instructions is intended as a guide for use in the preparation of maps by photogrammetric methods from Shoran-controlled aerial photographs. In general, the procedures vary from existing standard photogrammetric procedures only in so far as is necessary to apply this new type of horizontal control. The Shoran system measures the distance between an airborne set and a ground transponder. In the photographic application, the distances from the aircraft to ground stations placed at each end of a base line of known length are recorded at the instant of each aerial exposure. Shoran readings are first reduced to corresponding ground lengths, and the triangle then is solved for position of the photo plumb point.

2. Scope. These instructions contain the detailed information required in Corps of Engineers planning for Shoran-controlled aerial photographic missions and in using Shoran control in photogrammetric mapping. Also included, in order to provide a complete picture of Shoran technique, is a general discussion of Shoran principles, equipment, and airborne operating procedures. Inasmuch as Shoran control is suitable for original mapping, the instructions are concerned primarily with multiplex procedures. However, the use of Shoran with slotted templet and mosaic methods is covered sufficiently to permit employment of these mapping expedients when the occasion warrants. Detailed procedures required in determining distance between ground stations by Shoran measurements or in the adjustment of Shoran triangulation are not included. Knowledge of the material contained in existing manuals on map reading, topographic drafting, and photogrammetric mapping is presupposed.

3. Revisions to the Instructions. Although mapping with Shoran control is now feasible, the procedures herein outlined must be considered tentative since both the equipment and the mapping procedures are in the developmental stage. Present studies give every indication that accuracy and operating efficiency will be further improved as modifications and tests now in progress are consummated. New equipment and revised airborne procedures will require parallel changes in the mapping application if maximum utilization of the method is to be realized. Revisions will, therefore, be furnished from time to time as modified mapping procedures are developed.

4. Development. The term Shoran is a contraction of the phrase SHOrt RAnge Navigation. Although its tactical employment was greatly delayed, Shoran was one of the first radar systems to be developed during World War II. In fact, the initial Shoran idea was conceived in 1938 by the Radio Corporation of America. The first developmental model was delivered in February 1942 under contract with the Army Air Forces Aircraft Radio Laboratory and tested for use in navigating the bomb run and indicating release points for bombardment aircraft. Although the flight tests were highly satisfactory, quantity procurement was delayed since this country was then newly engaged in war and impetus had to be directed toward the development and procurement of basic essentials with which to equip a rapidly expanding Army. Finally, in the latter part of 1944, Shoran was put into tactical use for bombing vital pin-point targets in northern Italy. In rapid succession, targets that had been near misses by visual bombing methods were destroyed with the aid of Shoran. Further losses of airplanes and crews resulting from enemy action were sharply reduced because missions could be scheduled at night or during overcast conditions. Its extensive use was planned; but by the time the equipment could be made available in sufficient quantity, and personnel could be trained in its tactical employment, the European war was nearly over and targets were practically non-existent. Extensive plans were also made for the employment of Shoran in the war against Japan, but again the war ended before the plans could be put into effect.

The desirability of adapting this distance measuring instrument to mapping operations was apparent from the start. At the earliest opportunity tests to determine accuracy and proper mapping procedures for use with Shoran control were begun. Use of the system, both for triangulation and for controlling aerial photography, was investigated. Testing started in January 1944 and is still continuing. A recording camera designed to produce exposures synchronized with those of the aerial camera was developed so that the Shoran coordinates of each aerial exposure could be determined. Bombardment equipment was, and still is, used for the mapping work, although modifications have been made from time to time as methods of improving accuracy were revealed. Airborne and office procedures were designed to be employed with bombardment equipment in order that the system could be put to immediate productive use. Several design features, however, somewhat complicate its use in obtaining mapping control, and for this reason research is being continued. New equipment designed especially for Shoran mapping is also being developed, but several years will be required for its procurement, testing, and standardization.

5. Limitations of Present System. The Shoran system now in use will produce planimetric maps approaching peacetime standards of accuracy for 1:50,000 scale. Several factors affecting accuracy and operating simplicity, however, need further study. The effects

of meteorological conditions on radio wave propagation are still to be clarified, since the reduction from distance along the Shoran ray path to an equivalent distance on the earth's surface requires a knowledge of the true wave path. While the formulas presented in this manual give fairly reliable results, continuing studies may reveal desirable changes. Further study is also required to evaluate and correct for variations in the Shoran distance readings introduced by variations in strength of the radio signals. Although the primary effect of this "intensity error" is of a systematic nature, it may also introduce random errors into the finished map.

Another source of error results from the inability of the airborne operator to obtain perfect "pip" alinement at the instant of each aerial exposure. This adjustment, which is done manually, must be performed continuously during the photographic mission. The operation is a tiring one, especially at photographic altitudes, and undoubtedly introduces random errors in the finished map. Present equipment provides no method for determining or compensating for the errors thus introduced.

Future design changes and modifications in equipment or mapping procedures may cause some of the descriptions or methods herein outlined to become obsolete. The instructions will be revised from time to time, but minor changes will not warrant immediate republication; therefore, it should be borne in mind that some descriptions of procedures and equipment may not agree exactly with those encountered in the field. For example, the basic information required for determining distance will appear on the film from all Shoran recorders but auxiliary instruments such as the clock or the thermometer may be replaced by other instruments.

6. Responsibility. The Corps of Engineers are responsible for the specifications for Shoran-controlled mapping photography and the production of the completed photogrammetric map. They are also responsible for indicating the desired approximate locations of ground station sites with regard to existing ground control systems and for performing the comprehensive survey work necessary to strengthen, tie, and adjust Shoran control. The Air Force is responsible for the field selection of Shoran ground station sites and for the installation, maintenance, and operation of both airborne and related ground Shoran equipment. The Air Force is also responsible for initially locating and permanently referencing Shoran ground stations, for determining meteorological corrections and calibration constants, and for performing the field computations necessary in assuring conformance of Shoran data to the requirements of general specifications furnished by the using agency. The Corps of Engineers is responsible for the final adjustment and analysis of completed control networks resulting from Shoran triangulation by the line-crossing method.

7. Application. Shoran equipment is usable for obtaining photo control, for flight line navigation, triangulation, hydrographic surveying, and possibly for other distance measuring operations. Shoran-controlled photography can be applied either to multiplex or to slotted templet mapping. It also is suitable for determining over-all scale and position of otherwise uncontrolled mosaics and for preparing both semi-controlled and controlled mosaics.

The ability of the system to guide the photographic aircraft along a predetermined flight line is of great importance in photogrammetric mapping. In fact, this application often warrants the use of Shoran even in areas where existing ground control obviates the need for controlled photography. Many man-hours are lost if mapping projects are held up waiting for reflights or if the photography contains excessive or insufficient lateral overlap. Shoran flight line navigation permits flying with minimum side lap and assures obtaining a maximum area of gapless coverage at the first fine weather opportunity. In the few instances in which reflights become necessary, the system provides a positive method of quickly obtaining the necessary additional coverage.

In Shoran triangulation, ground station sites are selected at the corners of appropriate figures and all sides and diagonals measured by flying the airborne set across the lines. The network then is adjusted and the geodetic positions are established by a least-squares procedure somewhat similar to that used for normal triangulation with measured angles. For hydrographic surveying, the Shoran airborne set is installed on a survey ship and used to indicate position at the instant of each depth sounding. The U. S. Coast and Geodetic Survey is presently using this system in the preparation of hydrographic charts.

Only the applications of Shoran in obtaining photo control and in flight line navigation are of primary concern in this set of instructions.

8. Types of Shoran-controlled Photography. Shoran-controlled photography is applicable to photogrammetric mapping projects in areas where horizontal control is unavailable, or where the time required for establishing control of greater accuracy by ordinary ground methods is unwarranted. In most mapping assignments, ground stations can be tied to existing triangulation networks so that the finished map can be positioned with respect to the parallels and meridians. Where military necessity requires, however, maps positioned only with respect to two unsurveyed ground stations may be produced. In this method, ground stations having the proper geometric and range relationship to the unmapped area are selected in any convenient location and the distance between them is determined

by flying the airborne set across the line joining the stations. Shoran photography is then flown in the normal manner. The resulting map will have good internal accuracy although its absolute positioning will have to await geodetic ties either to the ground stations or to identifiable points within the map itself. Astronomic observations at both ground stations may, of course, be used for absolute position, but because of inherent inaccuracies of astronomic positions, considerable error may be introduced.

With present Shoran equipment, maximum map accuracy requires distance readings corresponding to each aerial exposure in the area being mapped. In other words, the aerial operations consist of normal overlapping coverage with accompanying Shoran recordings. Fully controlled photography of this type is termed Shoran "area coverage photography."

Another type of photo control involves the use of Shoran-controlled photographic strips in conjunction with existing uncontrolled mapping coverage. The control strips are flown at right angles to the existing photography and at intervals of approximately each six exposures along it. In this manner, they serve to replace the ground traverse lines that normally would be required at about this same spacing. Horizontal pass points for control of the mapping coverage are established after the cross flights have been scaled to the Shoran control. This type photography is called Shoran "cross flight photography." The scaling of the control strips to the Shoran positions and the establishment of the necessary pass points may be accomplished either by multiplex or by slotted templet methods. This flight pattern will not produce final map accuracies equal to those attainable with area coverage photography but considerable Shoran flying time is saved in areas in which existing mapping coverage is available. As Shoran accuracy is further improved, cross flight photography may become increasingly more important.

For reconnaissance mapping at scales of 1:250,000 and smaller, Shoran "control point photography" can be used. Here, Shoran-controlled exposures are used to pin-point identifiable points at intervals of thirty to fifty miles throughout the area under consideration. Ground positions determined from these photos then can be used in the preparation of small-scale maps by trimetrogon or other reconnaissance type mapping methods.

9. Shoran Flight Line Navigation. A "straight line indicator" for attachment to the airborne set is standard Air Force equipment and is issued to Shoran photographic units. This auxiliary instrument permits flight line navigation along straight lines that are referenced only to the ground stations, and is proving to be extremely valuable for work in areas where good flight maps are

unavailable. Where Shoran is used for photo control, the straight line indicator normally will be used for navigation. Flight lines preferably are laid out parallel to the line connecting the ground stations. However, the only restriction as to orientation is that the flight lines or their extensions must clear the ground positions by at least 30 miles.

If the straight line indicator is unavailable, flight line navigation may be accomplished by flying arcs of constant radii about one of the ground stations. The resulting curved flights introduce several undesirable conditions such as the centrifugal deflection of the camera level bubble, the creation of crab between exposures, and the inability to arrange flight lines to suit special requirements. However, these disadvantages are far outweighed by the certainty of obtaining good photographic coverage on the first mission. It should also be noted that the adverse effects are reduced as the flight radius increases. In this method of arc flying, the radius must always be at least fifteen times the flying height in areas where multiplex methods are to be used in the compilation process. This is necessary in order not to exceed the usable length of the Y-movement available for orientation of curved flights.

Another possible method of flight line navigation is by "precomputed coordinates." In this procedure, the proper distance readings from the aircraft to each ground station at regular intervals along a straight line are computed before take-off and the aircraft then is flown so as to pass, as near as possible, along this precomputed course. Considerable skill and experience on the part of both pilot and navigator are required to accomplish this type mission.

10. Accuracy. The Shoran system contains both systematic and random errors. When applied to map control, the systematic (mean) error will appear as a shift of the entire area with respect to the parallels and meridians. Deviations from the mean (random errors) will be evidenced as localized scale and azimuth errors within the map.

For many military mapping operations, deviation from the mean will have the greater significance since the relative positions of features will be of more importance than having the map in its correct geodetic position. Tests show that present Shoran equipment will locate two-thirds of the exposure stations to within about ±75 feet of true position, exclusive of the mean error. Multiplex maps compiled from this control will, however, give somewhat greater accuracy than would be expected from this statement. The methods later described provide for scaling the map to the best mean fit of all Shoran points and thus permit "averaging out" some of the random Shoran error. Multiplex test maps compiled in this manner, using area coverage, T-5 photography from about 20,000 feet, indicate that two-thirds of the detail points will have a relative accuracy of about ±65 feet, 90 percent of the points will be true to within ±105 feet, and no point will be in error over about 190 feet. These values are all exclusive of the mean map position error. They represent about the maximum accuracy attainable with Shoran in its present state of development and are presented here to indicate the capabilities of this new mapping tool. The approximate accuracies to be expected from other Shoran photogrammetric applications are given in later chapters where the various procedures are discussed in detail.

Whenever properly calibrated equipment is used during the photographic operations, the mean shift of the map sheets should never exceed about 50 feet. Even this error can be largely eliminated if one or two identifiable points of known position are available in the area being mapped. Under these conditions, the Shoran map is first compiled by one of the methods later discussed and the entire sheet then is "slipped" into position as indicated by the survey points. If several adjacent sheets are to be compiled, survey points in every second or third sheet probably will be sufficient.

11. Shoran in Large-area Mapping. It can be seen that, in Shoran, the surveyor has acquired another new and useful tool. With the aid of Shoran navigational methods large areas of gapless photography can be obtained in a minimum amount of time. Areas of approximately 2,500 square miles can be photographed in one 6-hour flight at a photographic altitude of 20,000 feet. Reflights will seldom be needed but, when necessary, they can be readily obtained. The simultaneous gathering of horizontal control saves many miles of laborious triangulation and traverse operations. Although the Shoran system itself provides no vertical control information, accurate altimeter readings at the instant of each exposure and properly spaced cross flights will reduce the number of elevation points that must be established by ground methods. In fact, if the elevation of only a few well-distributed points throughout the area (such as water surfaces) can be recovered and used in conjunction with the altimeter data, fairly reliable form lines can be sketched by multiplex methods without recourse to additional control (Chapters VII and VIII). The value of being able to compile even a good planimetric map without ever having to occupy the ground cannot be overestimated in military mapping.

By use of the line-crossing procedure, the Shoran system also provides the method for making the initial triangulation survey. Ground stations thus located then become the ground stations for use in controlling the mapping photography. It may even be possible to attain greatest efficiency by combining the two operations. Photographic work then could be concentrated on the rather rare cloudless days and line crossings could be accomplished on the days when photographs cannot be obtained.

CHAPTER II

PRINCIPLES OF SHORAN MAPPING

CHAPTER II

PRINCIPLES OF SHORAN MAPPING

1. General. Shoran is an electronic measuring system for indicating distances from an airplane to each of two Shoran ground stations. In operation the aircraft transmits radio signals to each of the ground stations. These signals are received and immediately retransmitted back along the same path. By automatic measurement of the time required for the signals to traverse each round-trip path, the airborne equipment obtains an accurate figure for the distances to the ground stations. This information, together with a knowledge of the flying height, permits computation of the horizontal position at the instant of each reading. Fig. 2-1 shows how the distance indications serve to fix the aircraft relative to the two ground stations. In areas where geodetic positions of the ground sets are known, the absolute airplane position may be computed.

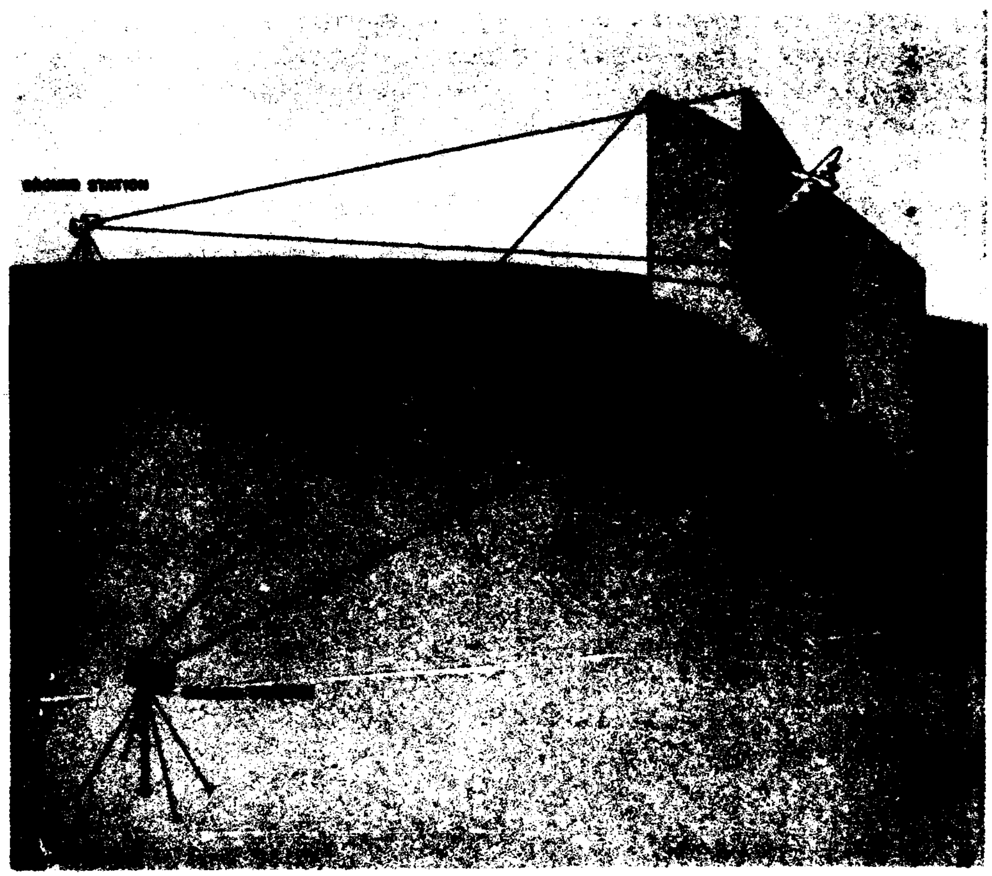


FIG. 2-1. TWO-DISTANCE "FIX" OF THE SHORAN AIRPLANE.

2. The Pulse System of Distance Measurement. The distance of the Shoran aircraft from each ground station is determined by means of the "echo-timing principle." This echo-timing method measures the time required for a short train of radio waves (called a "pulse") to travel over the distance and back to the starting point. In most radar systems, a round-trip radio path, for the purpose of distance determination, makes use of the fact that many objects act as good reflectors of radio waves. That is, radio pulses from the originating point, striking a wave reflecting object, are reflected, or re-radiated, to provide an "echo" signal which the originating station picks up. In this general type of system the reflecting surfaces usually are enemy aircraft or other types of non-cooperating targets.

Shoran uses a more effective method for providing round-trip paths. Instead of using a metallic object as a reflector, the ground station is, itself, a radio receiver and transmitter. With this system, the echo signal is greatly amplified. Fig. 2-2 illustrates the method used to determine the distance to a ground station. Here, the airborne set sends out a pulse of radio energy in the direction of the distant ground station, and simultaneously makes a kink or "pip" (designated the marker pip) on the screen of the cathode-ray tube. When the radio echo of this pulse returns from the ground station, it is received and made to produce a second pip (the echo pip) on the screen.

The airborne instrument is designed to produce a circular sweep on the face of the cathode-ray tube. The velocity of the sweep is constant (nearly) and is determined by the particular

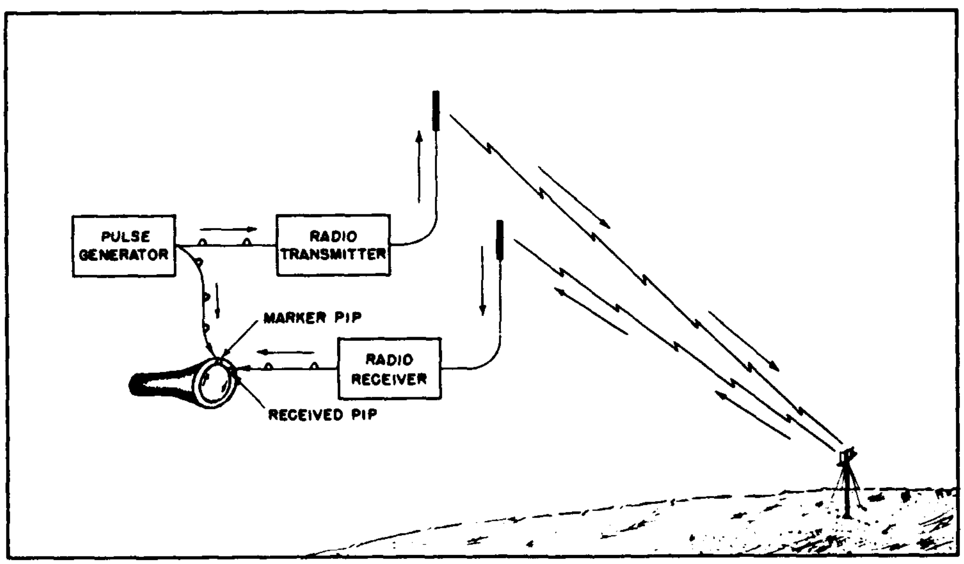


FIG. 2-2. DISTANCE DETERMINATION BY ROUND-TRIP PULSE TIMING.

scale setting selected. Pulses, generated at a constant rate, are fed to both the cathode-ray tube and the airborne transmitter. Since these pulses are synchronized with the sweep generator, the marker pip remains at a fixed position on the screen. The echo pulse, however, is delayed because of the time required for round-trip travel to the ground station and, therefore, forms a second pip on the "sweep circle" at some distance from the marker pip. The distance between the two pips is a direct indication of the time which elapsed between the formation of the first pip and the formation of the second. In other words, the distance between pips depends directly on the time required by a radio pulse to make the round trip over the distance being measured. Since radio pulses travel at a known speed (approximately 186,219 miles per second at sea level), this distance between pips also indicates the length of the round-trip radio pulse path, and therefore measures the air-line distance between the airplane and the ground station. The persistence of vision, the persistence of the oscilloscope, and the rapid rate at which the signals are repeated furnish the operator with continuous images of the marker and the echo pips.

With Shoran, the elementary method just discussed is modified in an important way. Actually, instead of directly using the distance between the pulses on the cathode-ray tube as an indication of distance, a "timing advance system" is used to produce transmitted pulses sufficiently earlier than the corresponding marker pulses so that a signal returning from its round trip arrives just in time to meet the corresponding pulse at the cathode-ray tube. The amount of time advance, or headway, given the outgoing pulse is variable and is calibrated so that the distance from the ground station is read directly. During operations, the device is adjusted until the leading edge of the echo pip coincides with that of the marker pip. The distance from the airplane to the ground station can then be read in miles on a dial scale and vernier counter.

In order to make possible a 2-circle fix (Fig. 2-1), simultaneous indications from two ground stations are obtained by sending pulses from the airplane in alternate groups, or trains, first to one and then to the other, and so on. Although most of the radio equipment is used jointly by both signal "channels" in the airborne set, separate timing advance systems are used so that the two Shoran mileages can be set and read separately. The two timing advance systems are driven by hand or geared to a motor drive. A single cathode-ray tube is used as an indicator. One marker pip appears at the top of the screen of this tube and two received pips show up on the sweep circle at positions depending upon the distances to the ground station. The set is so designed that one echo pip projects toward, and the other away from, the sweep circle center. When the two received pips are set in coincidence with the marker pip, the resulting readings of the dials are the distances of the airplane from each ground station. Fig. 2-3A shows the pattern on the cathode-ray tube with the received pips out of alinement with the marker. In Fig. 2-3B the pips are shown properly adjusted to coincide with the marker.

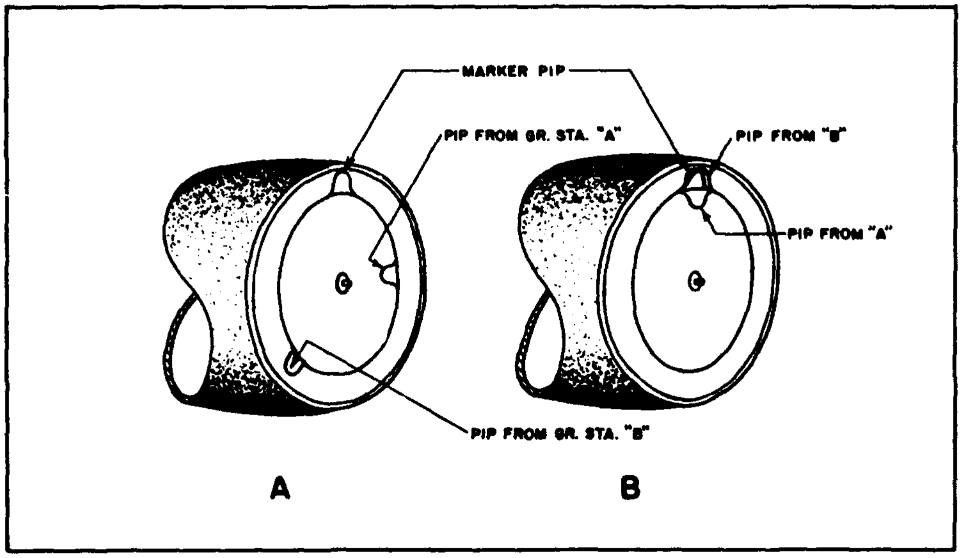


FIG. 2-3. PATTERN ON CATHODE-RAY TUBE. IN "A" THE THREE PIPS ARE SEPARATED FOR CLARITY. IN "B" THE PIPS ARE ALINED TO PERMIT TRUE DISTANCE RECORDINGS ON THE SHORAN DIALS.

In Shoran operations the designation of one ground station as the "Rate" station and the other as the "Drift" station occasionally will be encountered. This terminology is a carry over from the bombing application where the bomb run was made by flying an arc of constant radius about the Drift station. In mapping, the selection of one station as the Rate and the other as the Drift station is arbitrary and is used only as a convenience. Except possibly where arc flying is used in navigation, it is preferable to designate the ground stations simply as station "A" and station "B". Under this designation the westernmost station is called A and the easternmost is called B.

3. Equipment. A complete Shoran system consists of two similar ground stations at a considerable distance apart, and sets of airborne equipment installed in one or more airplanes. A "Shoran recorder," included as part of the airborne equipment, furnishes a photographic record of Shoran readings during photographic operations. The actuation of the recorder camera from the aerial camera intervalometer provides the information necessary for computing the plan position of each aerial exposure.

The ground station equipment, which is known as Radio Set AN/CPN-2, consists of an antenna mast, an antenna structure, a generator, a monitor, a receiver, a transmitter, cables, and other small items. The gasoline-driven generator furnishes the entire power required for the operation of a ground station. The monitor incorporates provision for tuning and for adjusting the total time required for the pulse to pass through the equipment. Provision is also made for reshaping the pulse, since distortion is introduced during transmission from the airplane. The antenna structure when erected upon the mast stands 50 feet above the ground. Horizontal radiation from the ground station antennas is moderately directional; the maximum signal intensity is in the direction toward which the antenna is pointed, and it decreases to about 50 percent at an angle of 30° on either side. In mapping operations one pointing of the antenna usually is sufficient, except under special conditions or where very large areas are involved. Equipment for one ground station is illustrated in Fig. 2-4. Five men can set up the station, make necessary adjustments, and have it ready for operation in approximately 8 hours. Gasoline consumption of the power unit is about 1 gph.

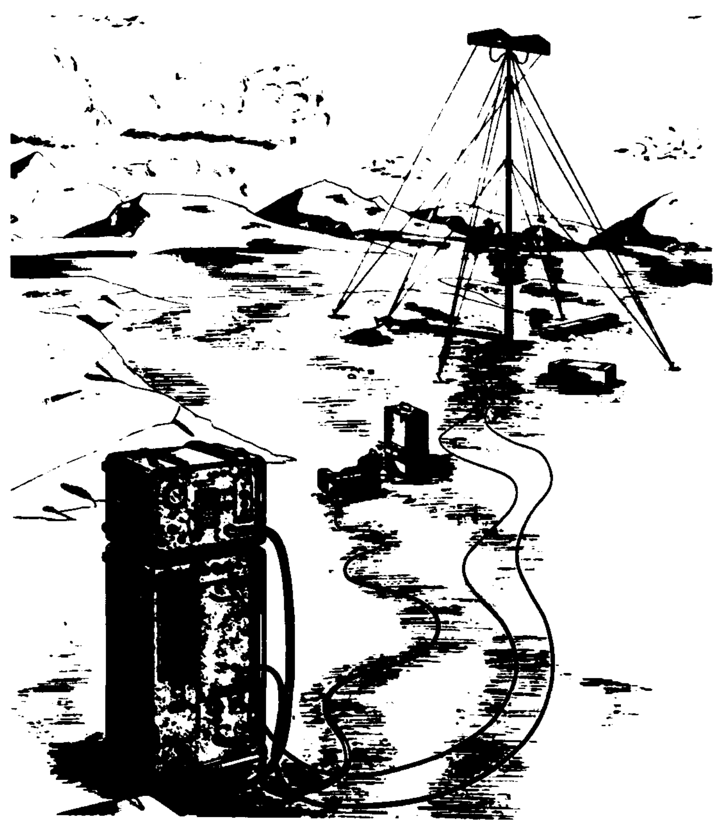


FIG. 2-4. SHORAN GROUND STATION.

The airborne equipment is known as Radio Set AN/APN-3. It consists of a receiving antenna, a transmitting antenna, a receiver, a timing unit, a transmitter, cables, and mounts. The timing and receiver units are built into one component and must be positioned in the aircraft so as to permit the operator both to see and to have easy access to the front panel. As operation of the transmitter is practically automatic, it may be installed in any convenient location in the plane. Both the receiving and the transmitting antennas are thin rods projecting about 12 inches from the fuselage and both are non-directional. The point midway between these antennas is the point at which the Shoran positions are effective. In photographic installations the aerial camera either must be placed near this mid-point or a compensating correction must be made during the computation step. The timing unit (Fig. 2-5) is the heart of the entire Shoran system, since the actual distance measurement takes place within this unit. Visible on the front panel of the instruments are various tuning dials, the face of the cathode-ray tube (1), large dials for rough adjustment of the time delay and indication of mileage (2), and mileage counters which serve as verniers in indicating distance to each ground station (3). A selector switch permits changing the scale so that one revolution on the sweep circle represents 1 mile, 10 miles, or 100 miles. With the sweep circle set at the normal operating scale of 1 mile per revolution, distance to the nearest 10 miles is read directly from large dials. The vernier counters give direct readings for the 1-mile, 0.1-mile, and 0.01-mile portion of the distance.

Fig. 2-6 shows the recording unit and Fig. 2-7 illustrates an exposure from the recording camera. This unit fits just below the timing unit and becomes an integral part of it. Fig. 2-8 shows the combined units installed for airborne use. Mileage counters in the recorder duplicate those of the timing unit and, in addition, provide space for the 100- and 10-mile portion of each reading. Synchronization of the two sets of counters is accomplished by means of a direct gear connection. With this arrangement, adjustments to the timing advance systems can be made by manipulation of the appropriate recorder mileage counter controls. Adjustment to each of these counters is made by means of a displacement knob and a variable speed motor. Since the displacement knobs are directly geared to the timing unit they can be used alone to maintain pip alinement. This is a purely manual operation, however, and since the airplane is constantly moving, would require a great deal of work. By use of the motors, each counter (and, therefore, the timing advance systems) can be set at a constant corrective speed that approximates the speed of the plane with respect to the ground stations. This greatly reduces the number of manual adjustments that must be made to the displacement knobs. The regulator for each motor is placed just behind its corresponding displacement knob to permit the operation of both with the same hand. Even with this

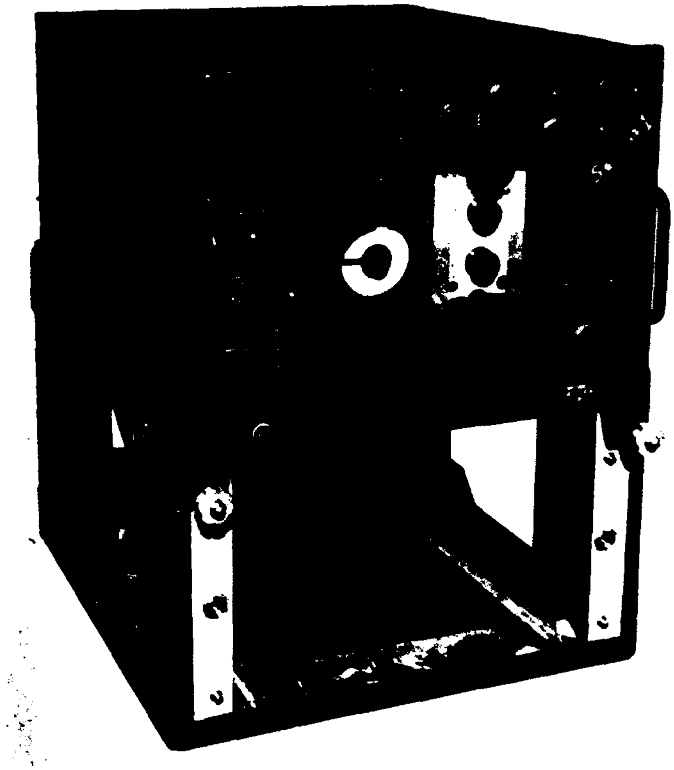


FIG. 2-5. SHORAN TIMING UNIT.

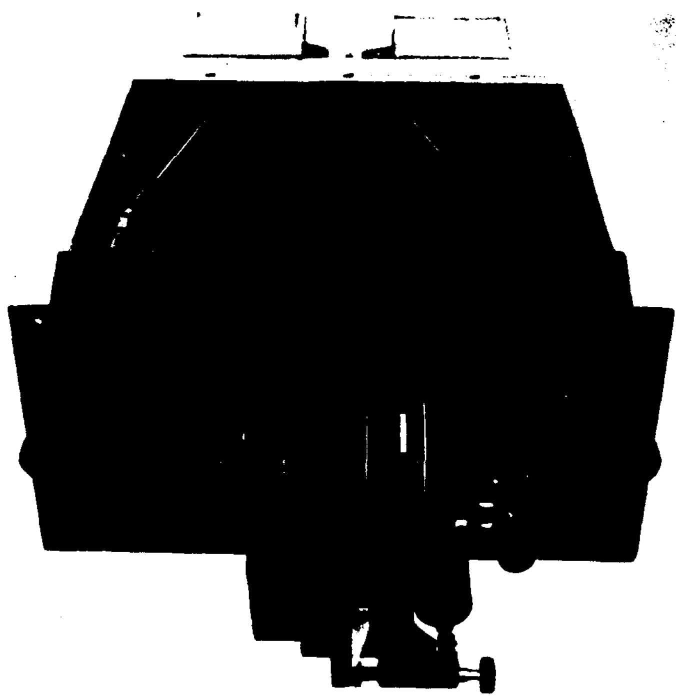


FIG. 2-6. SHORAN RECORDER.

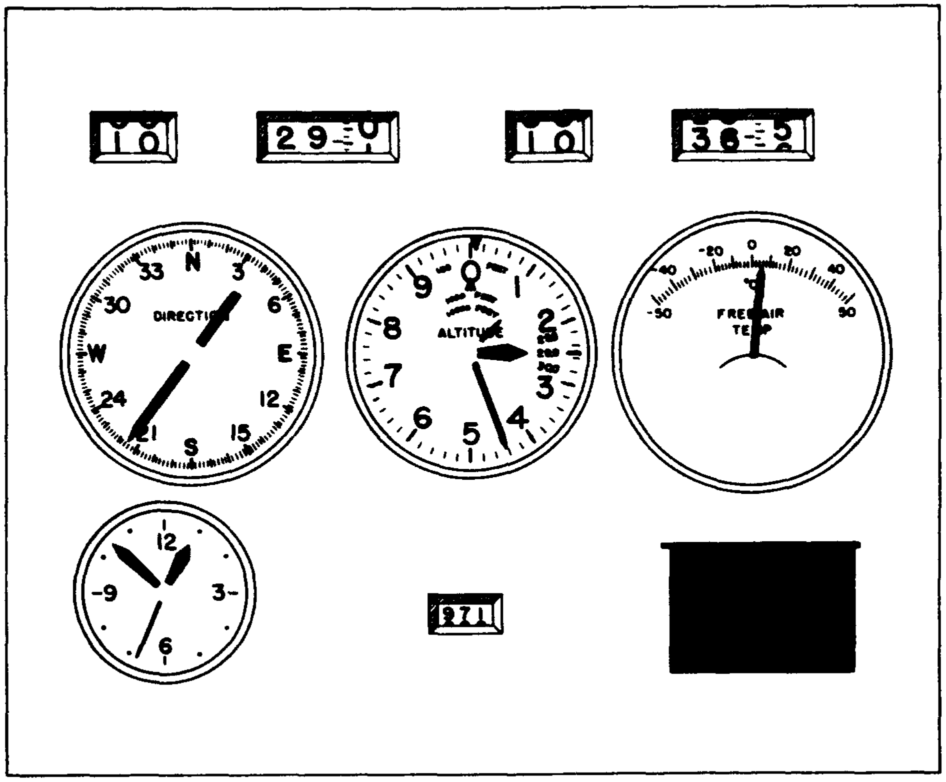


FIG. 2-7. SHORAN DATA FILM.

arrangement, operation of the airborne set necessitates constant manipulation with both hands (one "rate" and one "displacement" knob for each of the two ground stations) and requires difficult manual coordination which can be obtained only through practice and experience.

The recorder photographs are taken by a standard 35-mm moving picture camera, modified to expose single frames upon receipt of impulses from an intervalometer. Each recording shows the counter reading to each ground station, a compass giving the heading of the aircraft, an altimeter, a thermometer, a clock, a data card, and an exposure counter which has been synchronized with that of the aerial camera. The illustrated exposure (Fig. 2-7) shows that, when this picture was taken, the airplane was 102.904 miles from one ground station and 103.652 miles from the other. The figure in the third decimal place is obtained by interpolation. Information furnished with the photography must indicate to which ground station each of the counters refer. The small pointer of the altimeter reads in 10,000-foot units, the medium length pointer in thousands of feet, and the longest pointer in 100-foot units. The flying height indicated on the sample exposure is 12,440 feet above sea level. Although both are actuated from the same intervalometer, certain undesirable design features in present recorders

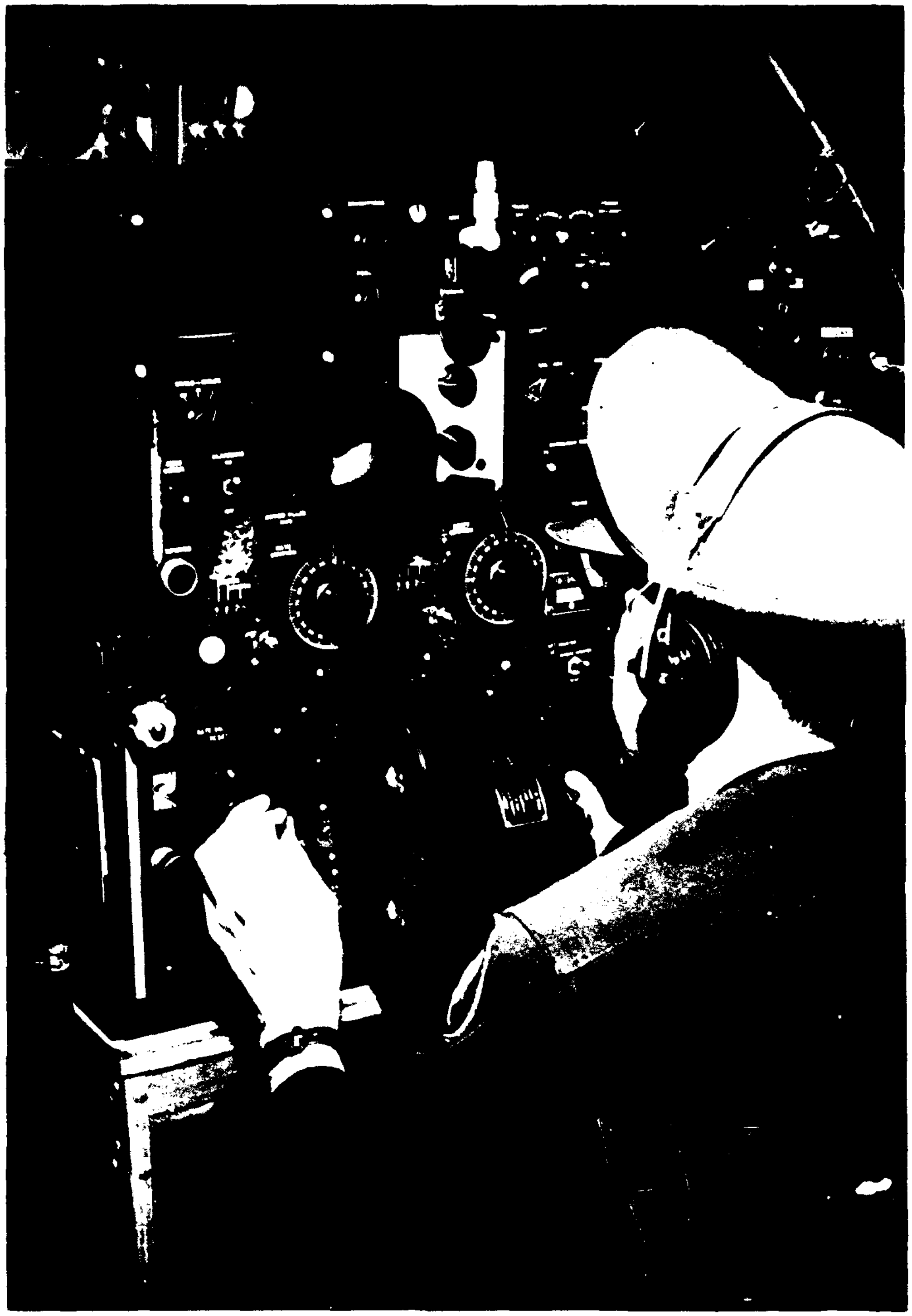


FIG. 2-8. AIRBORNE INSTALLATION OF SHORAN TIMING UNIT AND RECORDER.

require each aerial camera -- Shoran recorder installation to be individually calibrated to assure perfect synchronization.

4. Characteristics of Wave Path. Shoran waves, like light waves, travel in straight lines in a vacuum, and are refracted downward when they are traveling through the atmosphere. The amount of refraction of the Shoran rays, however, is somewhat greater than that of light waves. Fig. 2-9 illustrates the effect of atmospheric refraction. Bending of the path is greatest near the ground, but the path approaches a straight line at higher altitudes where atmospheric pressure and moisture content become less and less. It can also be seen from Fig. 2-9 that the maximum horizontal range of a Shoran airplane from either ground station is dependent upon the height of the ground station, flying height, refraction of the ray path, curvature of the earth, and elevation of the terrain along the ray path. A much clearer picture of the wave path is given by using the concept of a flat earth. Here, the earth is assumed to be a plane and the ray path is assumed to contain the effects of both refraction and curvature. Fig. 2-10 shows this representation of the Shoran ray path. Under the conditions shown, the maximum range of the equipment is given by the following formula:

$$\text{Range in miles} = 1.36\left(\sqrt{H - G} + \sqrt{K - G}\right)$$

where
- H = Altitude in feet above sea level of aircraft
- K = Height in feet above sea level of ground station antenna
- G = Height in feet above sea level of terrain at low point of Shoran ray path

Use of this formula must be limited to areas where the terrain in the vicinity of the low point of the path is level and at a fairly constant elevation above sea level. Distance from the ground station to the low point of the path is given by the formula:

$$M_O = 1.36\sqrt{K - G}$$

where
- M_O = Distance in miles from ground station to low point of Shoran ray path
- K & G as before

Actually, M_O and G are interdependent, so that one cannot be determined until the other is established. However, in many instances where terrain is relatively flat for a considerable distance from the ground station, the formula gives a reliable estimate of extreme range. If intervening hills obstruct the "line of sight," other formulas, or even the construction of a profile, may be required. These problems are discussed further in Chapter III.

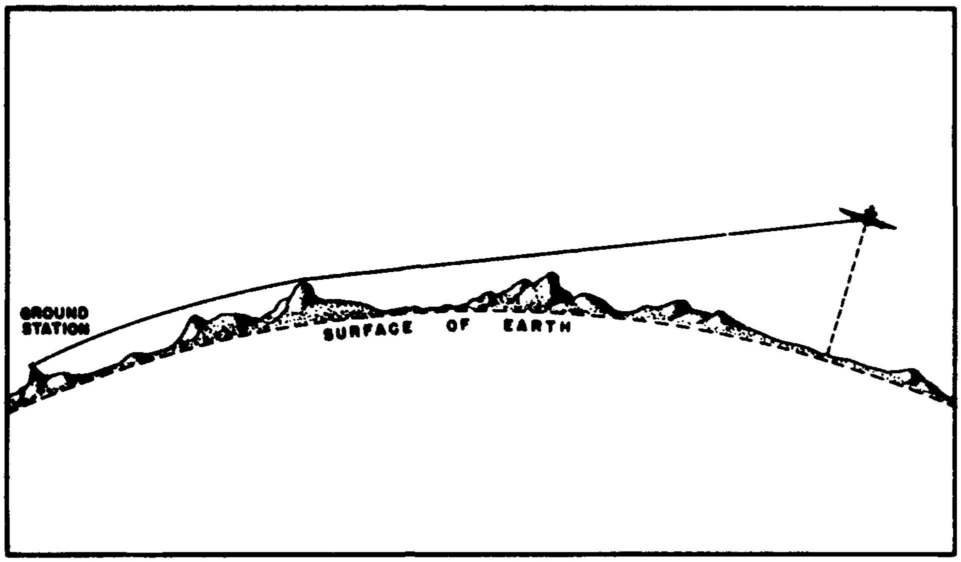


FIG. 2-9. PATH OF SHORAN RAY.

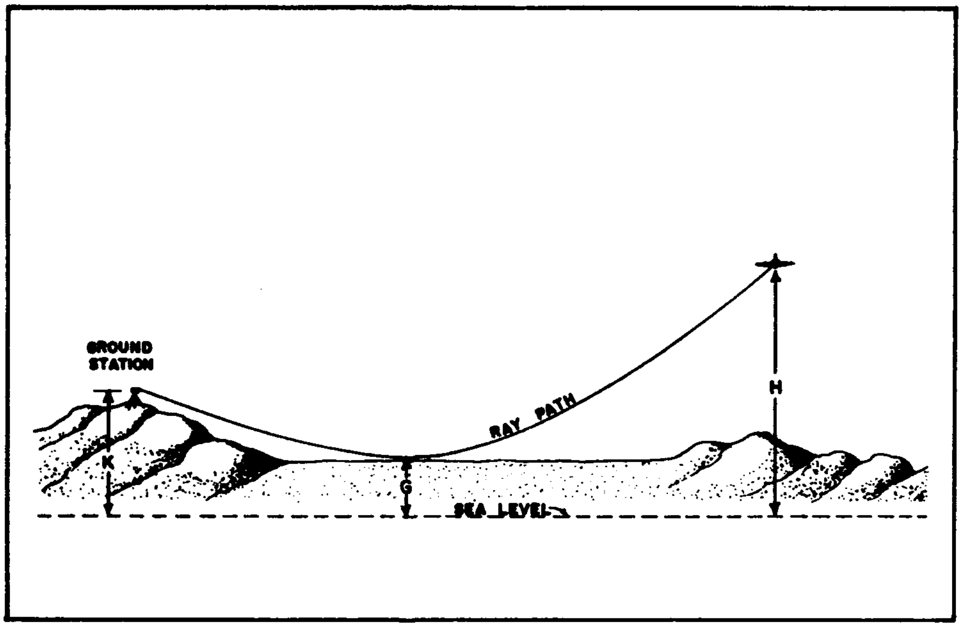


FIG. 2-10. FLAT EARTH CONCEPT FOR DETERMINING HEIGHT OF SHORAN RAY PATH.

The formula just presented gives fairly reliable reconnaissance values for the maximum horizontal range of the Shoran equipment. However, terrain conditions in the immediate neighborhood of the ground station and other local factors may introduce anomalies that will considerably modify values obtained by the use of this formula. Where it becomes necessary to work near the extreme range of the equipment, or where an alternate selection of ground station positions is possible, the advice of Air Force electronic specialists should be obtained. It will also be found that atmospheric conditions at the time of Shoran operations will have a small effect on maximum range. On days when the moisture content of the atmosphere is high, increased refractions will enable the aircraft to receive signals at a distance slightly greater than the computed range, while under very dry conditions, the signals will cut out at a distance slightly less than the computed range.

5. Equipment Calibration and Adjustment. Shoran measures distance between the aircraft and each ground station as a function of the time required for a pulse of electromagnetic energy to travel the round-trip path. Since the pulse of energy is delayed a constant amount in passing through the ground station equipment, the airborne timing circuits are set to consider this delay. The factory adjustments of the airborne sets assume equal time delays in all ground sets, the delay being a constant equivalent to 0.1800 mile. This means that each airborne set is adjusted so that when it is receiving its own transmitted signal (that is, measuring a zero distance) the mileage counters will read 99.8200 instead of 0.0000. However, since many indeterminates affect the delay, it is necessary to calibrate and to determine the "ground station delay correction" for each ground station just prior to commencing Shoran operations.

It is also found that all airborne sets do not read 99.8200 when they are receiving their own signals. In fact, the "observed zero" in any one set does not remain constant but must be read and recorded at the beginning and end of each photographic mission if maximum Shoran accuracy is to be attained. The "correction of the observed zero from the reference value of 99.8200" is algebraically added to the mileage counter reading. This correction is determined as follows:

$$\text{Zero correction} = 99.8200 - R_Z$$

where R_Z = Zero observation

Pulse travel time is measured in the airborne timing unit by means of a timing oscillator. The equipment design is such that true path distance is recorded when this oscillator frequency in cycles per second is equal to one-half the velocity of electromagnetic propagation in miles per second. Electromagnetic wave velocity, which is equivalent to the speed of light, is 186,219 miles per second at sea level under standard atmospheric conditions. As Shoran measures the loop travel, it is convenient to use the loop velocity of 93,109.5 miles per second. Correct Shoran readings, then, will be obtained when the airborne timing oscillator is adjusted to a frequency of 93,109.5 cycles per second. When the timing oscillator frequency differs from this reference value a correction is required.

The oscillator in the airborne set is not temperature stabilized; consequently, the wide range of pressure and temperature conditions encountered between ground elevation and photographic flying height preclude reliance on the frequency stability of this oscillator. To overcome this difficulty each ground station is equipped with a temperature stabilized and compensated crystal oscillator circuit and just before starting the photography, the airborne timing oscillator frequency is adjusted to obtain synchronization with the ground station oscillators. Actually, the two ground stations will not be exactly on the same frequency, and so the airborne timing oscillator is adjusted to the mean of the two frequencies. This airborne adjustment of the timing oscillator furnishes a valuable check on the equipment, since a difference of frequency between the two ground sets of more than 2 cycles per second indicates the necessity of recalibrating the ground station oscillators.

The method used in calibrating and adjusting the ground station timing oscillators does not always produce a frequency of exactly 93,109.5 cycles per second. This procedure does not seriously handicap the computations, however, since a "timing frequency correction" is easily applied if the frequency used during the Shoran operations is accurately known. The following formula gives the required value:

$$\Delta S = \frac{F - 93{,}109.5}{F} \cdot S$$

where ΔS = Timing frequency correction in miles
F = Actual timing frequency in cycles per second
S = Shoran distance in miles

Where maximum accuracy is required, it is also necessary to apply a "timing non-linearity correction." This error results from slight irregularities in the functioning of the "phase-advance" devices which form a constituent part of each timing advance system. The correction, which should never exceed ± 0.006 mile, is furnished in the form of tables or curves by the photographic unit if requested in the specifications for photography.

A rather large error in the Shoran measurements may be introduced by variation of the signal intensity in different sections of the field of coverage. This effect is caused by the fact that one wave path travels directly from the ground antenna to the aircraft while a second travels from the ground antenna to the ground and is then reflected to the airborne set. The difference in length of the two paths is too small to form two echo pulses on the scope. The only effect is that the signal strength is increased or decreased, depending on whether the two signals are in or out of phase. If the intensity level during ground station calibrating and the mean intensity level during operations are radically different, a considerable mean error in measurement may be experienced. If one or two identifiable points of known position are available within the area to be mapped, this and other types of systematic errors can be eliminated during the map compilation process. Otherwise, the constant portion of the intensity error can only be removed through adjustment of an associated Shoran triangulation network, provided that the same ground station calibration installation is used for both the photography and the triangulation. In Shoran-controlled photography of a relatively small area, for which a complex Shoran triangulation net is not required and is not available, the constant error can only be estimated from past experience. The Air Force unit will make the necessary estimate if requested. Errors caused by a deviation of intensity levels from the mean, which cannot be controlled at present, must be expected. Such errors can only be treated as random.

Another possible source of error is in the synchronization of the aerial camera, the Shoran recorder, and the separate altimeter recorder that is used in most mapping operations. The recorders, as presently designed, operate at the end of the intervalometer pulse, whereas the aerial cameras operate at the beginning of the pulse. In order to eliminate this time lapse, a special delay circuit is placed between the intervalometer and the recorder and is adjusted until proper synchronization is obtained. Very little error results if proper precaution is observed. However, since each aerial camera-recorder installation must be individually calibrated, it is important that this adjustment be called for in the specifications for photography. Failure to obtain good exposure synchronization between all cameras will introduce serious errors in the resulting map.

It is also necessary to correct for an error which results from the necessity for placing the airborne receiving and transmitting antennas at different locations. The correction (designated C_{AA}) is equal to one-half the distance between the two antennas; it always increases the Shoran measurement, and rarely exceeds .001 mile. The value will be furnished with the photography.

6. <u>Velocity Correction to Shoran Distances.</u> The airborne Shoran set is an accurate time measuring instrument with mileage counters so calibrated that when the timing oscillator is tuned to 93,109.5 cycles per second, the distance to each ground station is

read directly in miles. This calibration must assume a constant propagation velocity for electromagnetic waves. However, the speed of radio waves is dependent upon atmospheric conditions and actually varies from point to point along the ray path. For this reason, a "velocity correction" must be made to each of the Shoran readings. In Shoran triangulation, meteorological conditions are accurately measured at the time of operations by flying a weather observer airplane along the approximate ray path from the Shoran airplane to each ground station. By recording temperature, humidity, and pressure at regular intervals along the path, true wave velocity can be computed and the necessary corrections applied. In normal photogrammetric mapping the refinement of weather observations at the time of photography is not required. Sufficient accuracy is usually attained by basing the velocity correction on average meteorological conditions. The method of computing these corrections, as later outlined, is based on the "N.A.C.A. Standard Atmosphere" with added mean U. S. annual vapor pressure at about 40° latitude. The maximum error in Shoran distances that will be introduced by deviation of atmospheric conditions at any particular time from that represented by the "Standard Moist Atmosphere" amounts to only about 1 part in 20,000. Errors of this magnitude are ordinarily insignificant in mapping operations. Greater accuracy requires velocity correction determinations by an experienced weather officer using meteorological data observed at the time of photography. These values are obtainable by the Air Force photographic unit but, if such refinement is required, they must be called for in the specifications for photography.

7. Reduction to Ground Distance. The Shoran distance reading, after correction for calibration errors and for variations in the velocity of propagation, gives true distance along the curved ray path between the airplane and the ground station. In order to reduce this corrected Shoran distance to ground distance at sea level, further corrections must be applied. These corrections are necessary because of the geometric relationship between the curved earth, the altitudes of airborne set and ground station, and the curved path of the Shoran ray. The basic formula for the computation of the ground distance is as follows:

$$M = 2Ra \text{ arc sin} \sqrt{\frac{4r^2 \sin^2\left(\frac{S_1}{2r}\right) - (H_1 - K_1)^2}{4(Ra + H_1)(Ra + K_1)}} \qquad (1)$$

where

M = Ground distance in miles

Ra = Mean radius, in miles, of earth along the line being measured

r = Mean radius, in miles, of Shoran ray path = $3959\left[2 + .95(H_1 + K_1)\right]$

S_1 = Shoran reading, in miles, corrected for calibration errors and for variations in propagation velocity
H_1 = Height, in miles, of airborne set above sea level
K_1 = Height, in miles, of ground station antenna above sea level

Angular values in the previous equation are expressed in radians. The Ra term varies with mean latitude and azimuth of the line being measured since the earth is a spheroid.

Another form of this equation is obtained by making several assumptions, expanding the basic equation to a more usable form, and then correcting the resulting value by the use of charts or tables. Velocity and calibration corrections can then be added to produce equations of the following form:

$$M = S - A \tag{2}$$

$$A = \frac{2.3920}{10^8} \cdot S(H + K) + \frac{1.7935}{10^8} \cdot \frac{(H - K)^2}{S} - \frac{0.24848}{10^8} S^3 + \frac{1.6083}{10^{16}} \cdot \frac{(H - K)^4}{S^3} + V - C + B \tag{3}$$

where
M = Ground distance in miles
S = Uncorrected Shoran distance reading in miles
A = Total correction to Shoran reading in miles
H = Height of aircraft in feet
K = Height of ground station in feet
V = Shoran velocity correction in miles
C = Total electronic calibration constants in miles
B = Corrections for the various assumptions (values from tables in miles)

Formula (1) or formulas (2) and (3) will give equally good results but the use of the latter two will ordinarily prove most satisfactory in photogrammetric map compilation work. A detailed discussion of the solution of formulas (2) and (3) by use of computation forms and tables is given in Chapter V.

8. Station Angles. The error in distance from the airplane to either ground station is dependent upon the accuracy of the Shoran system. The accuracy of position which results from the distance measurement to both ground stations is further dependent upon the horizontal angle subtended at the airplane by the ground stations. The effect of "station angles" on position accuracy is

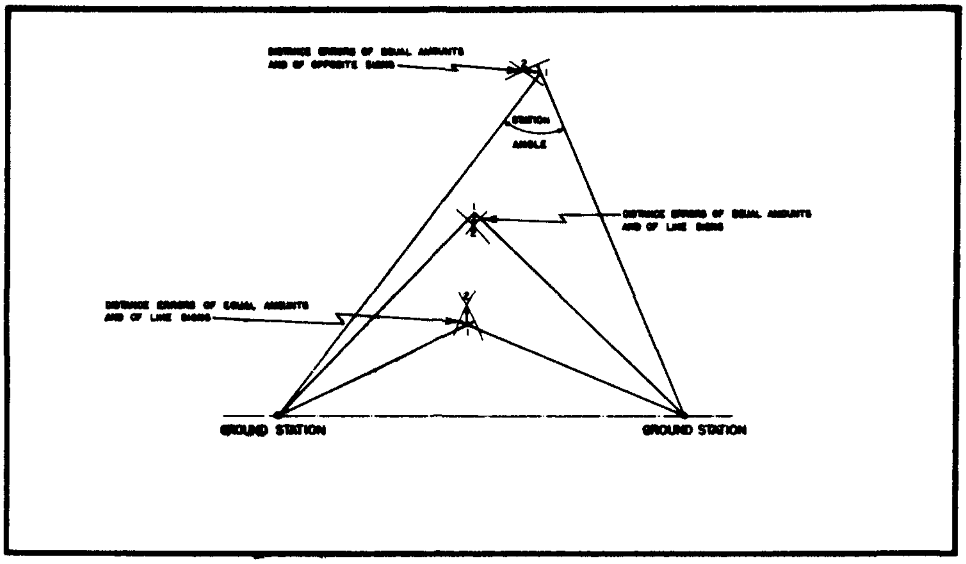


FIG. 2-11. EFFECT OF STATION ANGLE VARIATION ON SHORAN POSITION ACCURACY.

illustrated in Fig. 2-11. In each case, point 1 is the true position and point 2 represents the apparent location as determined by Shoran measurements, all of which are assumed to be in error by the same amount, E. If both distance measurements are either too long or too short, position error is a maximum when station angles are large and it is a minimum when station angles are small. Where distance measurements contain errors of opposite sign, position errors are a maximum when station angles are small. Since random errors in the Shoran system are just as likely to be plus as they are minus, the strongest position determinations occur with station angles of 90° and the greater the departure therefrom, the greater is the region of uncertainty.

The curves of Fig. 2-12 show the relationship between station angles and position errors in terms of the Shoran distance error, E. For example, with a 90° station angle and 100-foot errors in the Shoran measurements, the resulting position is in error by 1.41 times 100 or 141 feet. Had the station angle been 120° and the errors in both measurements been of like signs, a position error of 2 times 100, or 200 feet would result. In order to exercise some control over the magnitude of the unavoidable error present in locating a point from two Shoran measurements it becomes necessary to place limits on the station angles. Angles of from 60° to 120° are presently considered desirable for mapping photography. Large deviations from these limits should be permitted only after consideration of the possible effect on map accuracy.

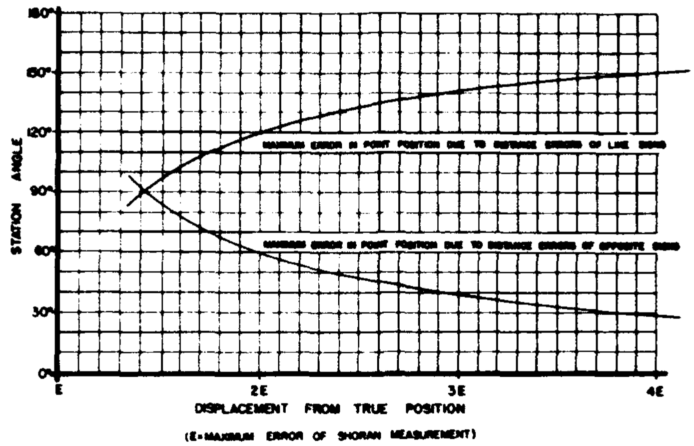


FIG. 2-12. CURVES SHOWING RELATION BETWEEN STATION ANGLES AND POSITION ERROR.

9. Shoran-controlled Photography. Shoran-controlled photography for use in photogrammetric mapping is performed in the normal manner with about 56 percent forward overlap between exposures and fifteen to thirty percent lateral overlap between flights. Exposure of the Shoran recorder at the instant of each aerial exposure provides the data necessary for computing the map position of each exposure. (A separate altimeter recorder is usually employed to provide more accurate values of flying height than those obtainable from the Shoran recorder altimeter.) Where only the distance between ground stations is known, exposure positions relative to the ground stations are determined. The information so obtained permits the preparation of a map, but since absolute position is unavailable, latitude and longitude cannot be shown. However, in the more usual case the ground stations are situated at, or tied to, first- or second-order triangulation stations, thus permitting the preparation of the map complete with parallels and meridians.

Random errors in the Shoran system prohibit absolute reliance in any one position. Maximum map accuracy depends upon scaling groups or strips of photographs to the best average fit of the corresponding Shoran positions. For example, in multiplex mapping a strip of about six models is first adjusted as a unit to obtain correct relative orientation. Next, the strip is scaled to the best mean fit of all Shoran points concerned. Detailed procedures necessary in the application of Shoran control to multiplex and slotted templet mapping methods are outlined in later chapters.

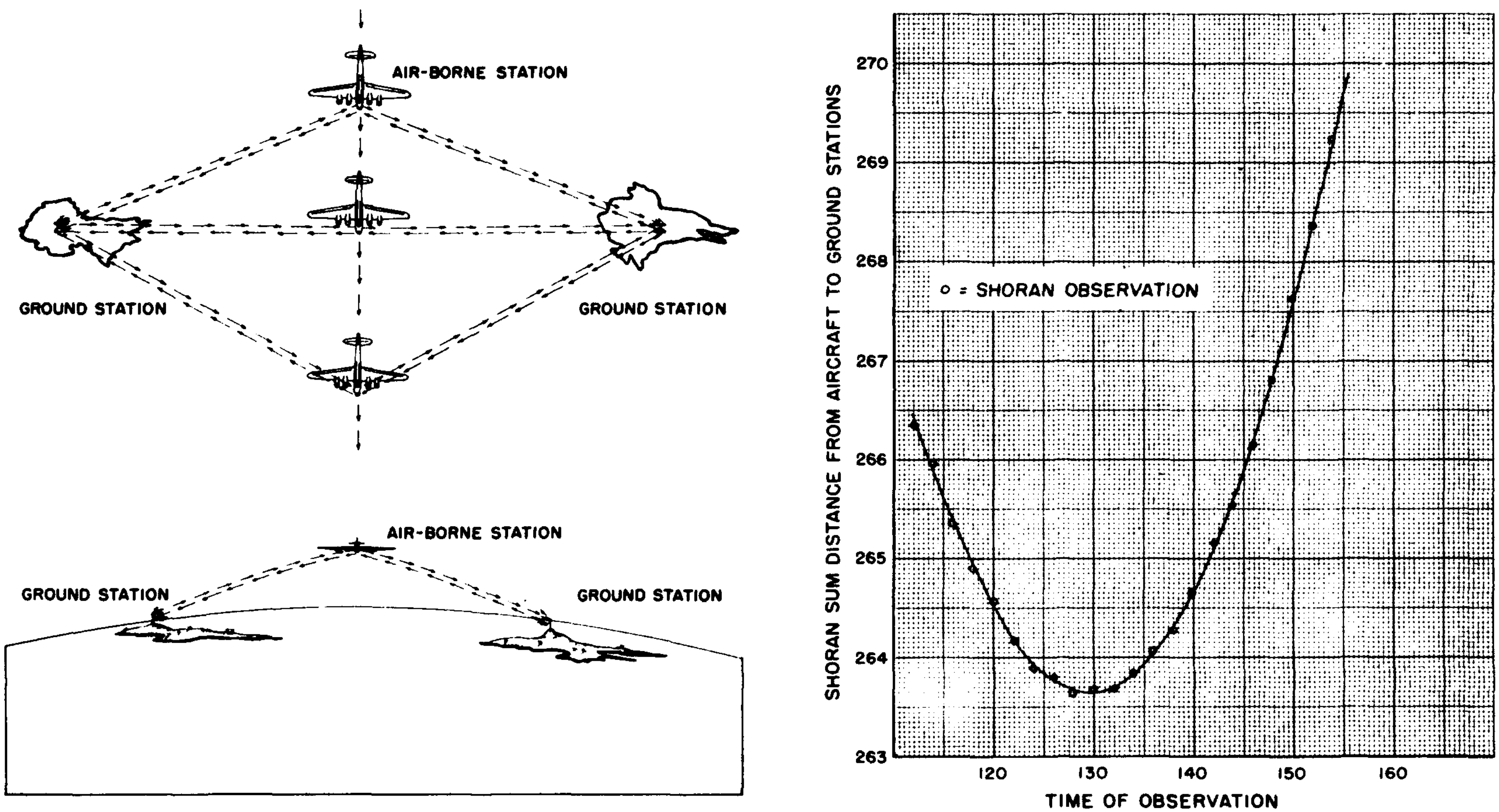


FIG. 2-13. PRINCIPLE OF SHORAN LINE CROSSINGS.

Shoran coordinates represent the map position of the airplane at the instant the aerial negative was exposed. Since the corresponding point on the aerial photograph is represented by the plumb point, it is extremely important to have a knowledge of photo tilts. Use of the photo principal points instead of plumb points (which implies no tilt) may introduce considerably more error than is inherent in the Shoran positions. In areas where considerable identifiable vertical control is available this problem is not serious. If vertical control is not available special techniques for recovering camera tilts must be employed in order to obtain maximum map accuracy. The multiplex solution to this problem requires the use of additional photographic flights at right angles to, and spaced at intervals of about each six exposures, along the regular mapping coverage.

10. Shoran Line Crossings. Another application of Shoran is its use in determining distance between two ground stations by a procedure known as the "line-crossing method." In this method, the airborne set is flown across the line joining the ground stations. Since the Shoran dials continuously read the distance to each ground set, the sum of the distances is a minimum when the airborne station is directly over the line. When the ground distance corresponding to each half of this minimum reading has been computed, the sum will be the required geodetic distance.

As the airplane approaches the line to be measured the sum of the distances to the ground stations continually decreases to a minimum at the actual point of crossing, and then again increases as the plane continues on its course. If the sum of the distances is plotted against the time of observation, a curve of the type shown in Fig. 2-13 will result. The minimum point of the curve represents the true Shoran sum distance at the point of crossing. During operations the necessary data are collected by actuating the Shoran recorder at a uniform rate of one exposure every two to three seconds. Several random errors in the Shoran system, including the inability of the airborne operator to maintain pip alinement, may cause the dial readings to be either too large or too small at any instant. To minimize these errors, the sum distances for about fifteen readings on both sides of the crossings are fitted to a parabolic curve by the method of least squares. The minimum point of the resulting curve then gives the most probable value for minimum Shoran distance.

If ground stations are situated at the corners of appropriate figures and all distances measured by the line crossing method, there results a triangulation arc in which the lengths of all sides are known. To gain maximum accuracy, complete meteorological data are obtained at the time of operation and all possible refinements are included in the computational and calibration procedures. Lines varying from fifty to over five hundred miles in length may be measured. Triangulation of low second-order accuracy is presently being obtained and, as better equipment and further experience is gained, it is expected that first-order accuracy will become possible.

CHAPTER III

OPERATIONAL PLANNING

CHAPTER III

OPERATIONAL PLANNING

1. General. The planning and execution of Shoran operations is a responsibility of the Air Force. It is, however, necessary to have a thorough understanding of some of the problems in order to prepare workable specifications. Requirements for Shoran-controlled photography may be separated into three general headings:

a. Mapping of an area not now covered with suitable mapping photography.

b. Control for an area where existing photography is considered adequate.

c. Positioning of targets or secondary control points.

In the first two instances the ultimate objective will normally be the preparation of accurate maps at scales of about 1:50,000. The third type is used in mapping work to position picture points at intervals of thirty to fifty miles. These points then become the control for small-scale maps that are to be prepared from existing vertical or tri-metrogon photography.

Use of Shoran-controlled photography in areas not previously covered with suitable mapping photography will be the problem most often encountered and is the one requiring the most detailed planning. It will also be found that absolute positions of the ground stations usually will be required in order that the final map can be correctly positioned with respect to a known datum. The present chapter places emphasis on this more general type of planning. If the preparation for this type mission is fully understood, little trouble will be encountered in planning other kinds of Shoran photogrammetric operations.

2. Preparation of Work Sheet. As in all aerial photographic planning, the best available small-scale map of the region is used as a work sheet. Strategic maps and aeronautical charts at scales of 1:500,000 or 1:1,000,000 serve the purpose very well, although other scales may be needed in individual cases. The area to be photographed is first outlined on the map. Next, all existing first- and second-order horizontal control both within and surrounding the area for a distance of 100 to 200 miles is examined with a view toward the selection of possible ground station positions. Third-order positions, where the surveys have not been carried for long distances from their tie to higher order stations, are acceptable but are not so preferable as points of higher accuracy. Although the Air Force unit will make the final selection of

ground positions, Engineer specifications must indicate the desired approximate locations and, if possible, should include alternate selections.

Existing control is given first consideration in the selection of possible ground locations. Where it proves impractical to locate the Shoran stations exactly over control points, they should be placed so as to reduce to a minimum the amount of surveying needed to establish the positions and elevations. Two ground stations will normally be sufficient unless extensive photographic coverage is required. They must, of course, be selected so that the photographic airplane will always be within Shoran range of both ground stations, and every effort should be made to keep station angles throughout the area between the limits of 60° and 120°. In ground site selection, the advantages of Shoran flight line navigation also should be considered. Since the straight line indicator probably will be used, the "base line" between the ground stations should roughly parallel the desired direction of flight. If arc navigation is to be employed, an effort must be made to select ground stations so as to give the most effective layout of flight lines. In this respect, it is well to avoid stations that would introduce very short flights of from two to five pictures across the corner of an area. Under optimum conditions two ground stations will permit coverage of a rectangular area of about 9,200 square miles on each side of the base, assuming ground stations at sea level and a flying height of 20,000 feet.

The use of ground station locations that require working near the extreme range of the equipment may sometimes cause trouble, since the signals may have a tendency to become weak and fuzzy. On the other hand, Shoran position errors caused by errors in the determination of true flying height and ground station elevation may become serious when photography is accomplished closer than about 50 miles to either ground station. Internal map accuracy will suffer from operations too near the ground stations unless special precaution is taken to obtain accurate values for the difference in flying height between exposures. For this reason, it is preferable to select ground stations so that no part of the area to be mapped will be less than about 50 miles from either station. It should also be remembered that, other things being equal, the nearer station angles can be kept to 90°, the greater will be the inherent accuracy of resulting Shoran positions.

3. Geometric Considerations. The first requirement in the selection of locations for ground stations is that the entire area be within Shoran radio range. This is determined by substitutions in the range formula of paragraph 4, Chapter II, or through use of the nomogram shown in Fig. 3-1. In preliminary planning, the formula may be simplified to the form:

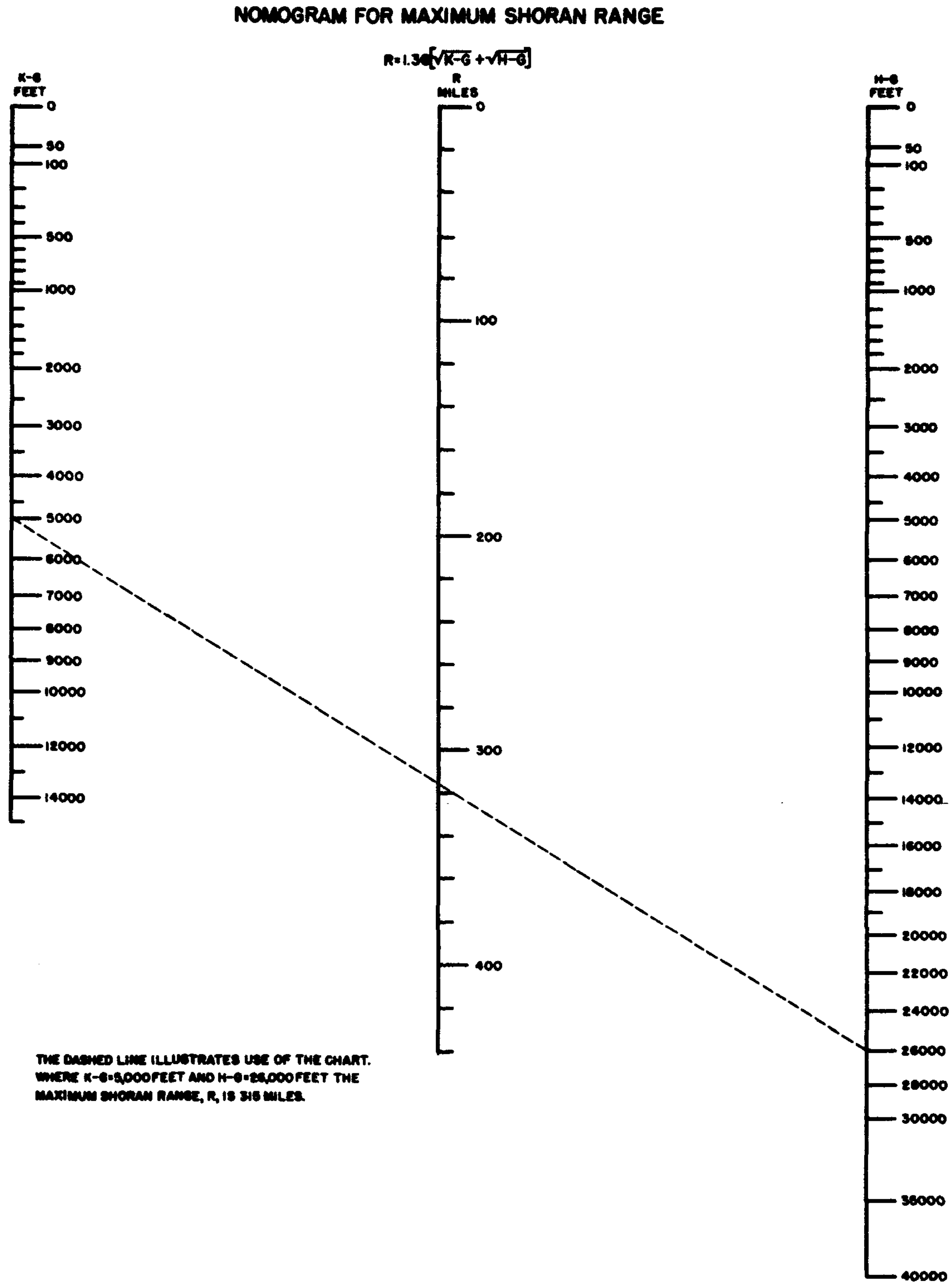


FIG. 3-1. NOMOGRAM FOR DETERMINING MAXIMUM SHORAN RANGE.

$$R = 1.36(\sqrt{H} + \sqrt{K})$$

where
- R = Horizontal range in miles
- H = Flying height in feet above general ground level
- K = Height in feet of ground station antenna above general ground level

The shaded portion of Fig. 3-2 illustrates the possible area of operations from two ground stations (A and B) where the range of the equipment is the sole consideration. If ground stations are at different elevations, it is necessary to compute separate range values for each station.

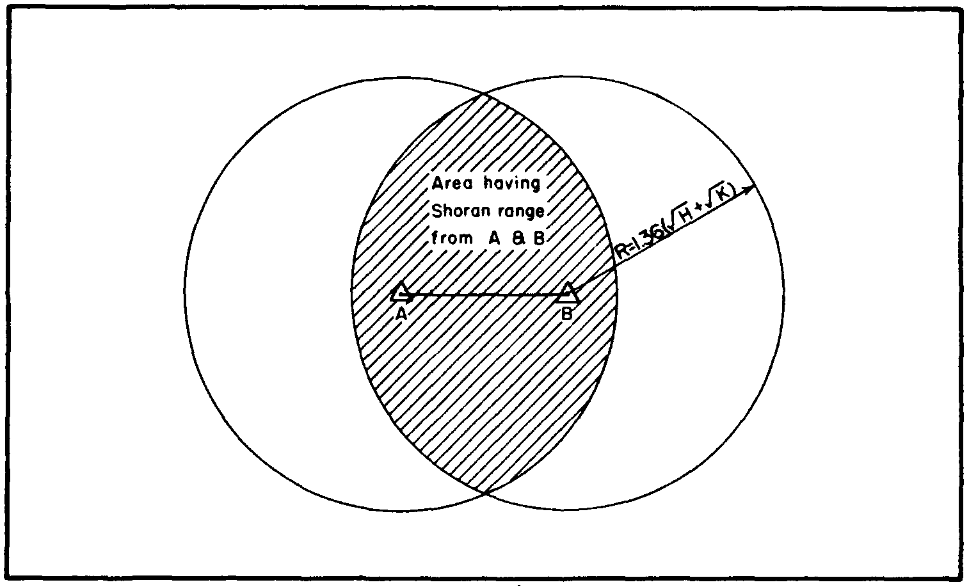


FIG. 3-2. RANGE LIMITATION ON SHORAN COVERAGE FROM TWO GROUND STATIONS.

The work sheet is also used to determine whether or not a pair of ground stations will satisfy the condition that station angles be maintained between 60° and 120°. The locus of points subtending any angle, α, between two stations is a circle passing through two stations having its center on the perpendicular bisector of the line joining the stations, and having a radius equal to $\frac{W}{2 \sin \alpha}$, where W is the distance between the stations. The shaded portion of Fig. 3-3 shows the area within which suitable station angles can be obtained. The radii of the limiting circles are determined by substituting 60° and 120° in this formula; a circle representing the location of the strongest possible station angles can be obtained by substituting 90°.

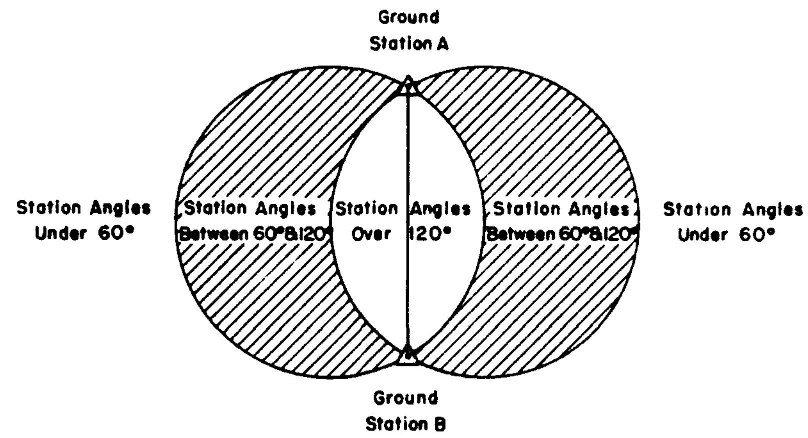


FIG. 3-3. AREA COVERAGE AS DETERMINED BY STATION ANGLE LIMITATIONS.

Where the area to be photographed is comparatively small, the selection of ground station positions usually is quite simple. Several possible combinations of station locations can often be spotted after a quick study of the existing control network. Range suitability is verified by comparing distances taken from the nomogram with distances scaled from the map. In the station angle test positions are, of course, considered in pairs. The area corners at which station angles will be a minimum and a maximum are usually determinable by inspection. Angular values are then computed by the formula:

$$\cos \alpha = \frac{M_1^2 + M_2^2 - W^2}{2M_1M_2}$$

where M_1 and M_2 = Distances from ground stations
W = Distance between ground stations

Here again, scaled distances are normally sufficient.

4. <u>Positioning of Ground Stations for Maximum Area Coverage</u>. If large areas are to be photographed and several ground station sites are needed, the planning becomes somewhat more involved. In areas with little or no existing control, provision must be made for tieing the stations together either by ground or by Shoran triangulation. Even in areas where existing control is available the distribution of points will not usually be suitable for maximum efficiency in the Shoran photographic operations. Careful

planning is required to obtain the proper balance between the amount of triangulation and leveling to be performed and the ideal ground station layout. Normal optical triangulation is slow and costly and, in areas where existing points are available, it may be wise to make these points serve. However, poor distribution necessitates the use of more ground station sites, and this results in the inconvenience of moving the ground equipment from station to station as the photography progresses. More important than this is the fact that sufficient equipment and personnel may not be available to operate more than a few stations at one time. This, in turn, limits the possible area coverage on the rather rare days when photography is possible. Considerable time is saved when the aircraft have a large area in which to operate and can choose alternate photographic areas when scattered clouds interfere with original plans. The time lost by an entire mapping organization in waiting for delivery of photography may be far more costly in the long run than the surveying required to obtain an efficient layout of ground stations.

The limiting effects of station angles and range on area coverage for one side of the base are illustrated in Fig. 3-4. Positions of the arcs representing the angular limits are dependent only upon the distance between stations and upon the angle, while the Shoran range from given stations is dependent only upon flying height. Above certain minimum altitudes and with a given station separation, the Shoran range will have no effect upon the

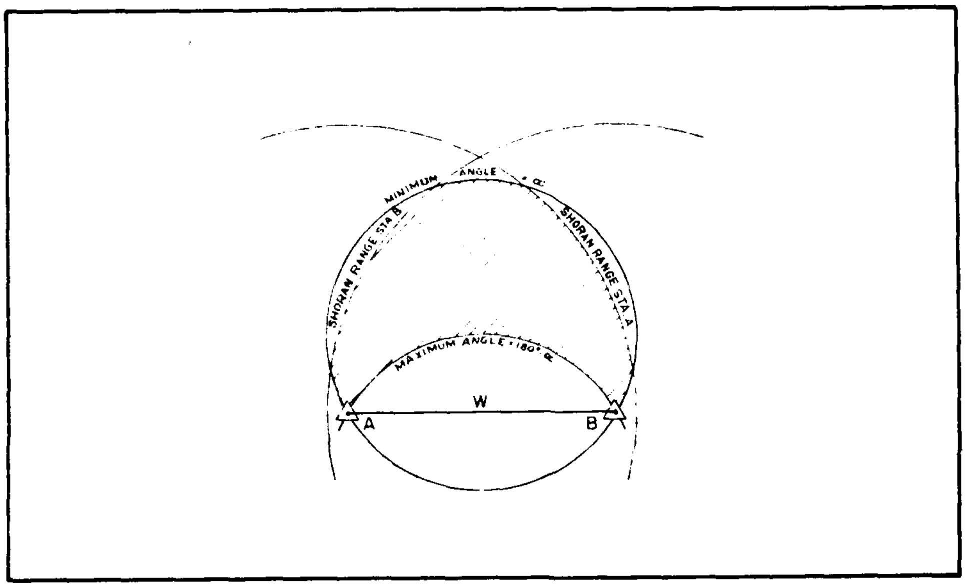


FIG. 3-4. LIMITING EFFECTS OF STATION ANGLES AND RANGE ON THE POSSIBLE AREA OF SHORAN COVERAGE (ONE SIDE OF BASE LINE).

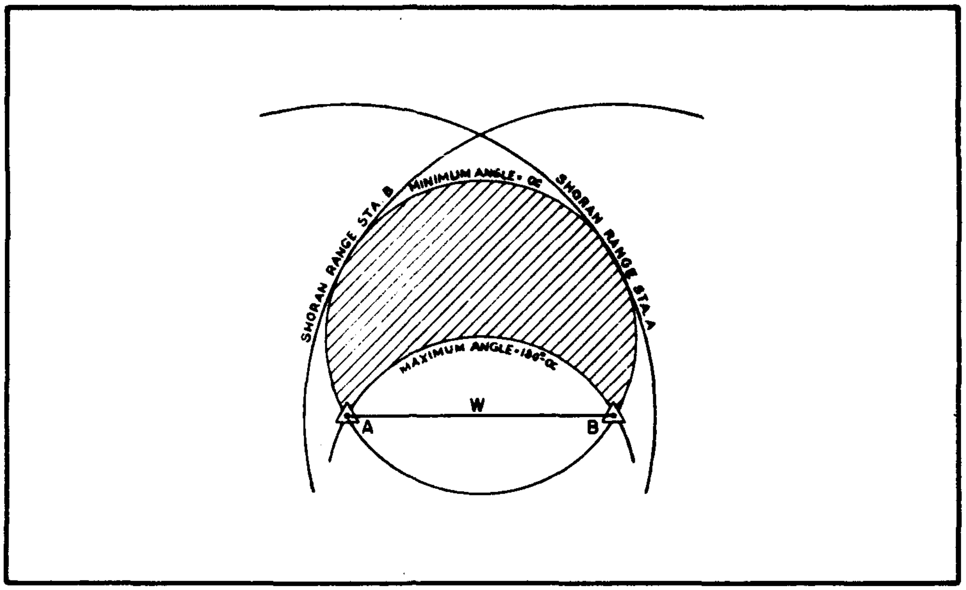


FIG. 3-5. IDEAL RELATION BETWEEN GROUND STATION SEPARATION AND SHORAN RANGE FOR MAXIMUM AREA COVERAGE.

area of coverage, since the circle representing minimum allowable angle will be entirely within the range of both stations. In order to cover a maximum area the relation between these variables should be as shown in Fig. 3-5. Here, the minimum angle arc is tangent to the maximum range arc. Since the flying height is usually determined by the characteristics of the desired map, and since the minimum desirable station angle has been set at 60°, it becomes necessary to arrange the distance between ground stations so as to attain maximum coverage. This ideal separation of the ground stations is obtained by combining the range and station angle formulas as follows:

$$W = \bar{R} \sin \alpha$$

$$= (1.36 \sin \alpha) \left(\sqrt{H} + \sqrt{K} \right)$$

or for $\alpha = 60°$

$$W = .87R = 1.2 \left(\sqrt{H} + \sqrt{K} \right)$$

where
W = Separation, in miles, of ground stations for maximum area coverage
R = Shoran range in miles
α = Minimum allowable station angle
H = Flying height in feet above ground level
K = Height in feet of ground station antennas above ground level

The formula assumes both ground stations to be at the same height, K. This introduces no serious errors in preliminary planning unless there is a considerable difference in height. It may also be helpful to note that, under these conditions, the formula for the distance from the center of the area to each of the ground stations is:

$$M = .64R = .83\left(\sqrt{H} + \sqrt{K}\right)$$

where M = Distance, in miles, from ground stations to area center for maximum coverage
R, H, & K as before

Under these maximum conditions the possible area of coverage in square miles for one side of the base is given by the formula:

$$A = .48R^2 = .89(H + K) + 1.78\sqrt{HK}$$

where A = Area in square miles
R, H, & K as before

The entire area between the limiting circles meets the geometric requirements for Shoran-controlled photography. The shape of the area, however, is such that part of it will not ordinarily be used. Normally, the principal interest will lie with the largest rectangular area that can be placed within the circular limits. Fig. 3-6 represents such a rectangle. The various relationships are as follows:

$$R = 1.36\left(\sqrt{H} + \sqrt{K}\right)$$

$$W = .87R = 1.2\left(\sqrt{H} + \sqrt{K}\right)$$

$$S_1 = .707R = .96\left(\sqrt{H} + \sqrt{K}\right)$$

$$S_2 = .35R = .48\left(\sqrt{H} + \sqrt{K}\right)$$

$$A = .25R^2 = .46(H + K) + .93\sqrt{HK}$$

where S_1 = Length, in miles, of side parallel to base
S_2 = Length, in miles, of side normal to base

If arc navigation is to be used, the largest possible rectangular area of coverage will be as illustrated in Fig. 3-7. Rectangular areas (Figs. 3-6 and 3-7) also have the advantage of being far enough from the ground stations to introduce no serious trouble from the inability to establish exactly the true photographic flying height.

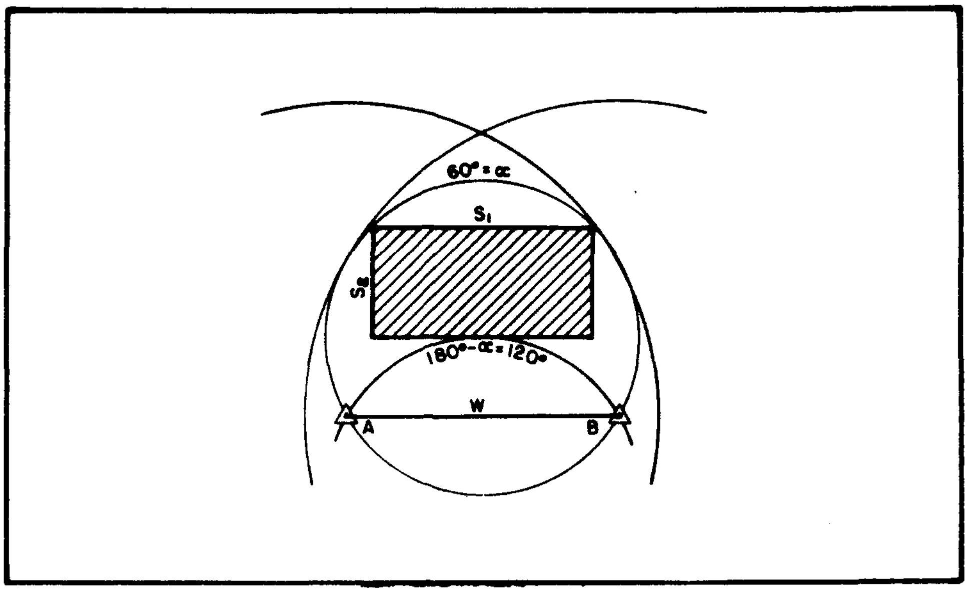


FIG. 3-6. ARRANGEMENT OF SHORAN GROUND STATIONS FOR MAXIMUM RECTANGULAR AREA OF COVERAGE (ONE SIDE OF BASE LINE).

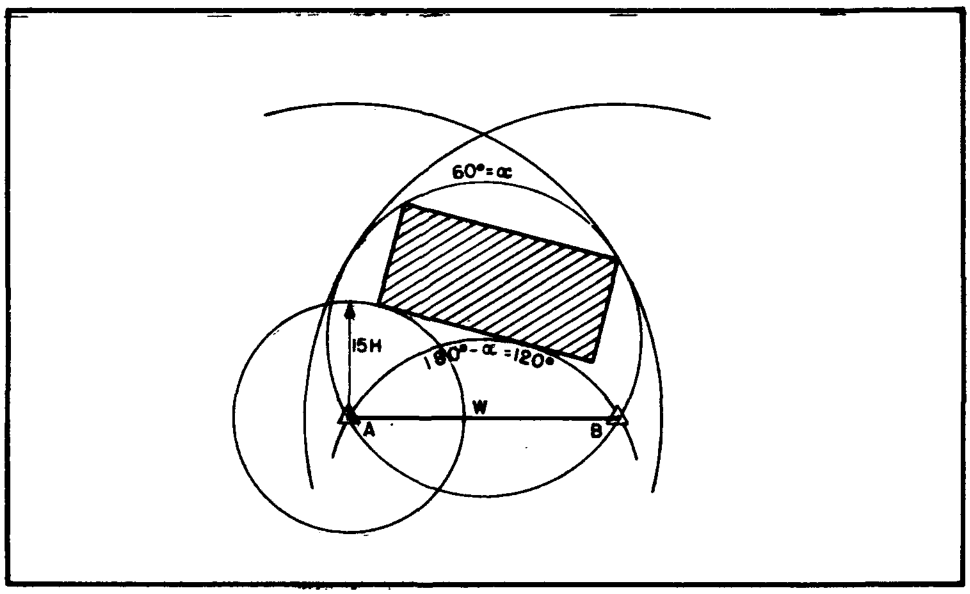


FIG. 3-7. LIMITATION OF MINIMUM RADIUS FOR FLIGHT LINE NAVIGATION ON MAXIMUM RECTANGULAR AREA OF COVERAGE.

Ground station arrangements for still larger tracts will depend upon the size and shape of the area and the layout of existing control. In such instances, an effort should be made to use the areas on both sides of the base. Fig. 3-8 illustrates an excellent arrangement for three pairs of stations. With this ideal layout, the entire state of Pennsylvania could be covered with Shoran-controlled photography from about 20,000 feet. The best station arrangement for any large area will ordinarily be an expansion of this basic 6-point solution.

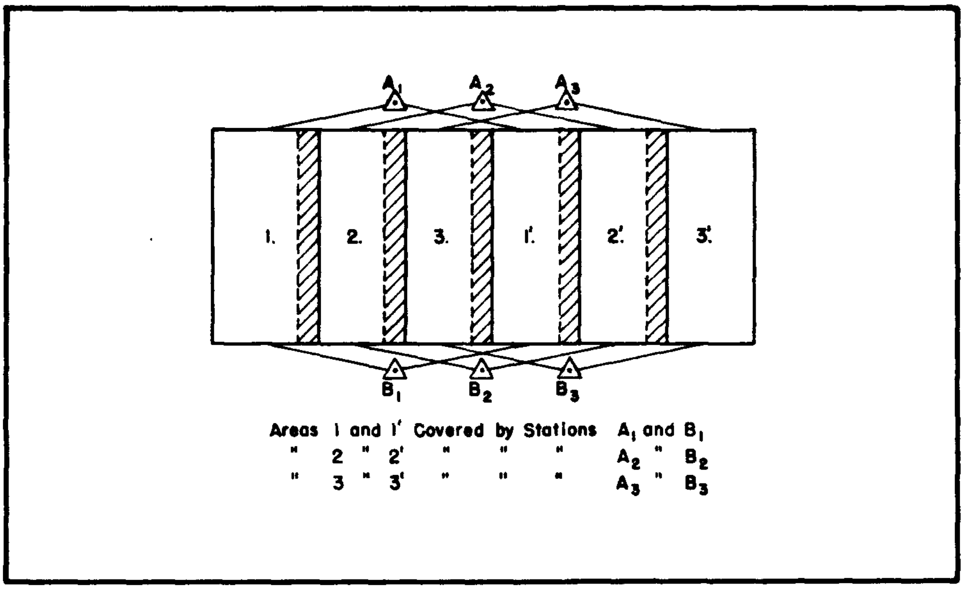


FIG. 3-8. SHORAN GROUND STATION LAYOUT FOR LARGE-AREA COVERAGE.

5. Obstructions to Wave Path. Since Shoran waves travel in approximately straight lines, hills and mountains along the proposed route from the ground stations may interfere with signal reception at the aircraft. In operations at nearly maximum range, the wave path stays very close to the ground for a considerable distance and, when the ground stations are above sea level, the waves may even travel for some distance at elevations lower than those of the stations themselves. Before final selection of a ground station position it may be necessary to determine whether or not the wave path will clear various obstructions at critical points along the proposed route. In rugged country it may even be desirable to prepare a profile between the ground station and the aircraft for comparison with the plotted position of the path. The following formula is used to find the elevation of path at any point:

$$h = K + \frac{H - K}{M} \cdot M_1 - .538M_1(M - M_1)$$

where

- h = Height in feet above sea level of path at a distance M_1 from ground station
- K = Height in feet of ground station antenna above sea level
- H = Height in feet of aircraft above sea level
- M = Distance in miles from ground station to aircraft
- M_1 = Distance in miles from ground station to obstruction

Values obtained by this method must be used with caution, since the formula is only an approximation. Various phenomena concerning electromagnetic wave propagation are not yet fully understood and, therefore, preclude reliance in any method of predicting path height. Values from the formula are probably conservative, but they should be accurate to within about ±500 feet in elevation under the conditions most likely to be encountered.

Another case that may often be encountered is illustrated in Fig. 3-9. Here, the ground station position is fixed as a result of other considerations and an obvious obstruction limits the maximum range to a smaller value than would be given by the formula of paragraph 4, Chapter II. It may still be desirable to know how far from the ground station the aircraft may work under given conditions of flying height. This answer is given by solving the previous height of path formula for M and substituting $M = R$.

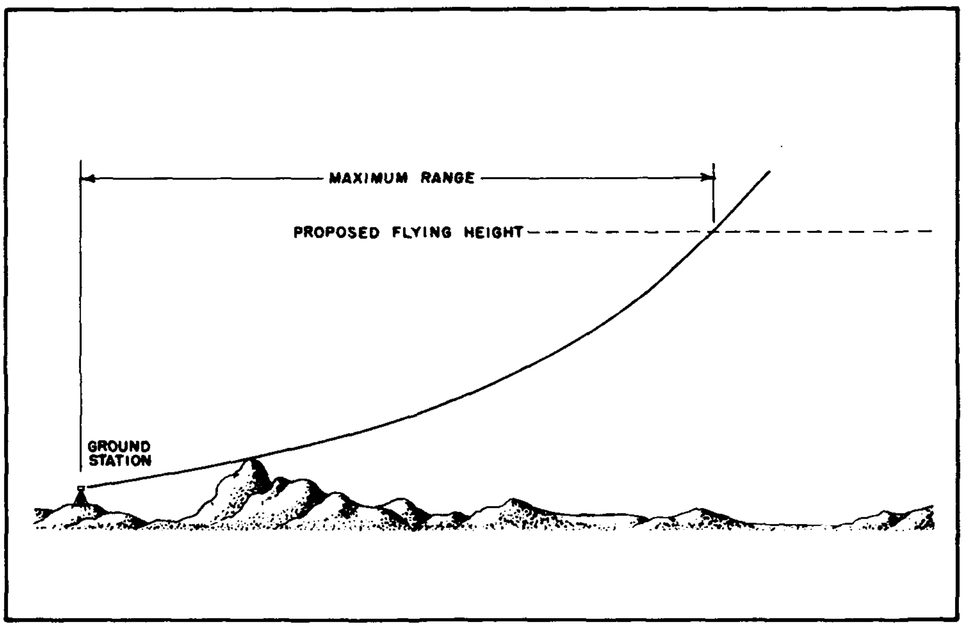


FIG. 3-9. LIMITING EFFECT OF AN OBSTRUCTION ON SHORAN MAXIMUM RANGE.

$$R = \frac{1}{2}\left[M_1 - 1.85\left(\frac{h - K}{M_1}\right)\right] + \sqrt{\frac{1}{4}\left[1.85\left(\frac{h - K}{M_1}\right) - M_1\right]^2 + 1.85(H - K)}$$

where
- h = Height in feet of obstruction
- K = Height in feet of ground station antenna above sea level
- H = Height in feet of aircraft above sea level
- M_1 = Distance in miles from ground station to obstruction
- R = Maximum range in miles

When no maps are available from which to obtain the height of the obstruction (h), observations of vertical angles at the ground station site will furnish valuable information. The tangent of the vertical angle then can be substituted for the $\left(\frac{h - K}{M_1}\right)$ term in order to solve for range. Under these conditions it may also be necessary to use an estimated value for M_1. Care should be taken to use the tangent as a negative quantity in the event that the observed vertical angle is minus.

6. Final Selection of Ground Station Sites. A tentative selection of ground station positions having the required geometric and range relationships may be made from the work sheet. This study, however, is only the first step. Air Force electronics specialists must make a further analysis to assure suitability from the standpoint of radio reception. Since terrain conditions in the immediate neighborhood of the ground station have a considerable effect on Shoran transmission characteristics, an on-the-spot reconnaissance of each site is normally required. It will sometimes be found that terrain conditions are much more suitable at some spot a short distance from a control point than they are right at the marker itself. When this is so, the survey tie between marker and antenna is usually a simple operation that will not prohibit the use of the more desirable location.

A field examination of the various possible sites is also needed to evaluate their comparative merits as to accessibility. Ease of transportation is a major consideration both in the initial placement of equipment and in the maintenance of adequate supplies of food, water, gasoline, and replacement parts. As placement and operation of ground stations is an Air Force responsibility, locations at, or near, airfields are the most desirable. Normally, all equipment is flown in cargo planes to the nearest airfield and it must then be hauled in jeeps or small trucks to the station site. This haul by surface vehicles should be kept to a minimum. Existing triangulation points are often located on high ground, and for this reason they may be very desirable from the standpoint of Shoran range. However, this same fact may limit the facility with which the necessary equipment can be transported to the site. Ground station equipment, together with radio equipment used in maintaining communication with the Shoran aircraft and base of operations, weighs about 3,000 pounds. Considerable housekeeping equipment will also be needed unless the site is located near a town or a military establishment. The total weight of all equipment, living facilities, and provisions for about 2 months is close to 9,000 pounds. In an emergency, two men at each station can furnish intermittent Shoran service, but the usual complement is five. If guards are needed, the required complement will be still greater. The length of time necessary to complete the mission at a station will depend upon the required amount of photography and upon the frequency with which good photographic days occur. If an extended stay is needed and if the transportation route is difficult, the supply problem may become serious.

Consideration also should be given to the facility with which communications can be maintained with headquarters and with sources of supply. In out-of-the-way places, the communications radios must serve this need; therefore, thought must be given to the radio transmission characteristics of the station site. The possibility of obtaining telephone service should be considered when the system is operated in populated areas.

7. Preparation of Flight Maps. The Air Force units will normally prepare the necessary flight maps although, where special photography is needed, such maps may be included as part of the specifications for photography. If arc navigation is to be used, flight paths will appear as arcs about one of the ground stations. Straight line indicator flights will roughly parallel the Shoran base. Flight maps supplied by the Corps of Engineers will be on a scale suitable for showing the boundary of the area to be photographed, the desired flight paths, and the proposed ground station sites. While these maps may not be suitable for use during the actual aerial operations, they will serve as a basis for planning by the photographic unit.

CHAPTER IV

AERIAL PHOTOGRAPHY

CHAPTER IV

AERIAL PHOTOGRAPHY

1. General. The photography obtained during Shoran operations must meet specifications for mapping coverage. In all cases tilt and crab should be held to a minimum, and forward overlaps should be kept within the range of fifty-three to sixty percent. Calibration of the camera level bubble should be checked regularly to avoid introducing any constant tilt into the photographic strips. Flight lines must contain a minimum of six exposures, since the mapping procedures require that the photography be scaled to the best mean fit of several positions. When any part of a flight is rejected, the unacceptable portion must be covered by a reflight which overlaps each end of the acceptable portion by at least four exposures. The specified lateral overlap between parallel flights should be large enough to guard against gaps in the coverage and yet not unduly increase the number of required exposures. Where visual methods of flight line navigation are to be used, a side lap of twenty to thirty percent will be required, although the use of Shoran navigation should reduce this requirement to about fifteen or twenty percent. In addition, if the terrain is characterized by large elevation differences and if a 6-inch focal length camera is to be used, 1 percent should be added to the specified overlap for each 1 percent of ground elevation difference when considered as a percentage of the flying height. It is also desirable that vertical deviations of the airplane be held to an absolute minimum. Shoran computations are greatly simplified by assuming a constant flying height for large blocks of photographs, but this can be done only when the individual exposures are within about ± 100 feet of the mean.

2. Aerial Cameras. The use of a precision aerial camera is an important part of the Shoran operations. Most areas to be covered by this work will contain very little existing control, either vertical or horizontal. Though Shoran furnishes only horizontal positions, the final map accuracy is largely dependent upon the ability to recover photo plumb points successfully. Frequently, an effort will also be made to show contours or form lines on the final map. For these reasons, the photography may have to be used to bridge between widely separated vertical control points or even to establish elevation differences from a knowledge of the altimeter readings appearing on the recorder film. This type of work can be accomplished by multiplex methods with a fair degree of satisfaction but only when an accurately adjusted calibrated camera has been used. Where a photogrammetric determination of flying height must be made for use in the reduction computation, a knowledge of the exact calibrated focal length and frame dimensions is mandatory. The Air Force Type T-5 or T-11 cameras are ideally suited for Shoran photography.

3. <u>Recorded Information</u>. The data appearing on the recorder film supply a large part of the information used in computing the Shoran position of each exposure station. In order for this information to be of value, the film in both aerial and recorder cameras must have been exposed at the same instant and with exposure counters synchronized for proper cross reference. Even though the same intervalometer operates all cameras (Shoran recorder, altimeter recorder, and aerial camera), undesirable design features of the present equipment would cause the recording film to be exposed at some constant time interval later than that of the aerial camera were it not for the use of a delay circuit between the recorder and the intervalometer. The amount of time delay necessary varies with different camera-recorder-intervalometer combinations and, therefore, requires the calibration and adjustment of each installation. It is important that this adjustment be called for in the specifications for photography. Sometimes the counters may fail to operate properly and cause different numbers to register on simultaneous exposures from different recorders. If this occurs, recourse must be made to an examination of the time indicated on the navigation watches that appear in all exposures.

The mechanical linkage between the timing unit and the recorder occasionally produces an even 10- or 100-mile error in one of the recorder distance readings. Any such errors usually are introduced before the start of a mission and remain constant throughout all exposures. To guard against map errors from this source, the photographic specifications should call for a tabulation of the distances indicated on the timing unit at the instant of one exposure near the beginning and another near the end of each mission. A later comparison of these manual readings with the recorded distances will indicate immediately whether a constant correction must be made.

The recorders are designed for use either with photography or in the gathering of data for Shoran triangulation. The information actually used in photogrammetric mapping is obtained from the distance counters, the exposure counter, the altimeter, and the data card. Each Shoran recording also shows a clock, a thermometer, and a compass giving the heading of the aircraft, for use primarily in the line-crossing operations. Recorders being developed will provide the following additional information:

a. Error meter.

b. Tilt indicator.

c. Differential altitude.

d. Radio altimeter.

e. Air speed indicator.

f. Psychrometer readings.

The error meter will furnish information concerning pip alinement at the instant of each exposure and thus will permit corrections to the Shoran positions that will undoubtedly result in improved accuracy. If a tilt indicator with sufficient accuracy can be developed, it will provide a simple method of recovering photo plumb points without recourse to ground elevations. A knowledge of differential altitude and of radio altimeter readings may be of value in bridging or extending vertical control. The remaining additional readings are being included to supply meteorological data for use under conditions in which the utmost accuracy is required. Since an alternate selection of recorders may be available to the photographic unit, it is advisable to state requirements in the photographic specifications.

4. <u>Special Flight Plans for Use in Areas of Limited Vertical Control</u>. Since Shoran positions are effective at the photo plumb points, errors in tilt determination are reflected directly as errors in horizontal position. The following table lists the plumb point displacement introduced by tilt errors for photography from various flying heights.

Plumb Point Displacement at Various Flying Heights

Tilt Error	5,000 Ft (ft)	10,000 Ft (ft)	20,000 Ft (ft)	30,000 Ft (ft)
0° 05'	7	15	29	44
0° 10'	15	29	58	87
0° 30'	44	87	175	262
1° 00'	87	174	349	524
2° 00'	175	349	698	1048
3° 00'	262	524	1048	1572

A study of this table indicates the large emphasis that must be placed on the problem of tilt determination. During the photographic operation every effort must be made to keep the aerial camera as near level as possible, especially in areas where the available vertical control is insufficient to permit recovery of the plumb points on a large percentage of the photographs.

In order to eliminate these tilt errors as nearly as possible, a unique procedure requiring special photography is used for multiplex mapping of areas with scanty vertical control. Fig. 4-1 illustrates the necessary layout of flight lines for an area coverage mission. The terrain is first photographed in the normal manner with overlapping photos, parallel flight lines, and with Shoran recordings obtained for each exposure. The necessary additional photography consists of cross flights at intervals of about each six exposures along the parallel coverage. Cross flight photography should contain the usual fifty-three to sixty percent overlap, and should be taken from approximately the same height as the regular coverage. Since flying height differences are used in the determination of tilts, it is necessary that the use of an accurate, well-adjusted altimeter be specified when this type of photography is requested.

The manner in which this special flight plan serves to provide multiplex model orientation can be explained by reference to Fig. 4-2. The two auxiliary flights (1 and 2) are first used to obtain lines of correct relative elevations at each end of flight 3, and at right angles to it. Flight 3 then is oriented in the direction of flight by use of altimeter readings, and in the tilt (Y) direction by reference to the lines of relative elevations that were established from the cross flights. Auxiliary flights must always contain a minimum of six exposures and should preferably extend at least three exposures beyond the center line of any flight with which they are to be used.

Flight plans for other types of photogrammetric missions (control point, cross flight photography, and the like) in areas with little or no vertical control are developed in the same general way. All are based on the fact that quite reliable values for the tilt components in the direction of flight can be recovered if values of flying height differences are known. This, in turn, permits lines of relative elevations to be established along the strip center lines.

5. Control Point Photography. The flight plan for control point photography is shown in Fig. 4-3. Tilt recovery is facilitated by the flight line arrangement. The use of two strips also permits a check on the resulting control point position. Each flight must have the normal overlap of from fifty-three to sixty percent between photographs and must extend at least three exposures on each side of the point of intersection. The angle between flights is not critical and deviations of as much as 25° from the optimum 90° can be tolerated. Since camera orientation probably will not be recovered perfectly, increases in flying height will increase the position error. The magnitude of such errors, however, usually will be of very little consequence in the type of work for which control point photography is suited.

Sometimes the exact feature to be pin-pointed is covered in the specifications but frequently only the general area is

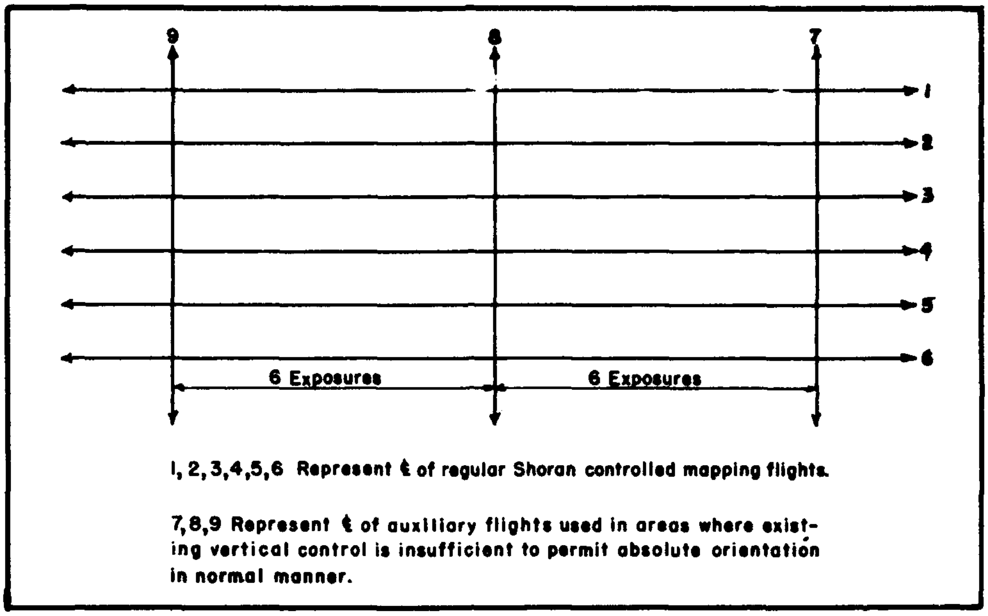


FIG. 4-1. FLIGHT PLAN FOR USE IN SHORAN MULTIPLEX MAPPING OF AREAS WITH LITTLE OR NO VERTICAL CONTROL.

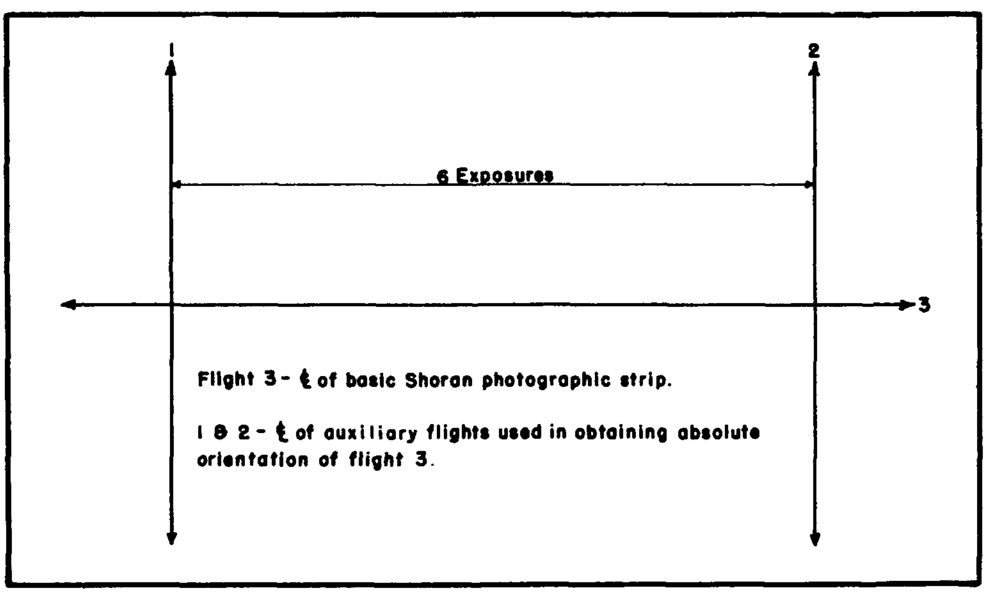


FIG. 4-2. FLIGHT PLAN USED FOR OBTAINING ABSOLUTE ORIENTATION OF ONE PHOTOGRAPHIC STRIP BY THE METHOD OF FLYING HEIGHT DIFFERENCES.

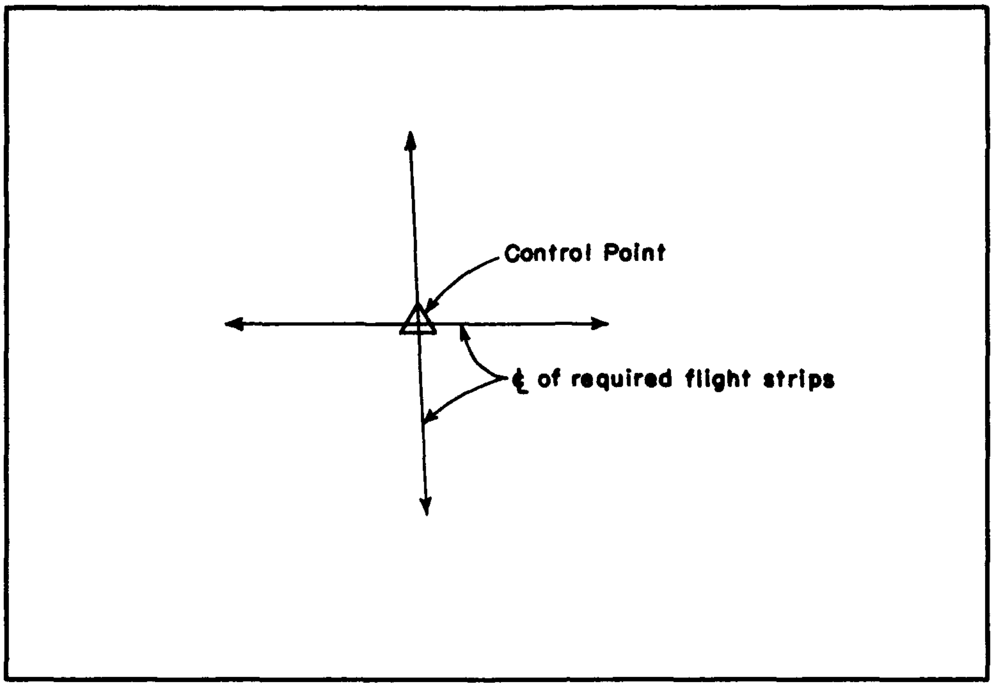


FIG. 4-3. FLIGHT PLAN FOR CONTROL POINT PHOTOGRAPHY.

designated and the detail point is selected during a short airborne reconnaissance just prior to obtaining the photography. Readily identifiable points such as stream intersections, peculiarly shaped lakes, and the like must be chosen so as to permit easy recovery on both the Shoran and the basic mapping coverage. Flights are then arranged so as to bring the detail point close to the intersection of the two center lines. The density with which control points are needed depends somewhat upon the map accuracy requirements although a spacing of less than about every 30 miles is seldom warranted. Where greater map accuracy is required from the basic coverage and a closer spacing of points would normally be indicated, Shoran-controlled cross flight photography will be found to be the more satisfactory solution.

6. Shoran Cross Flight Photography. It may occasionally be desirable to use Shoran in controlling areas for which existing uncontrolled vertical photography is available. In these instances, the Shoran photography will be flown in strips normal to the existing coverage and spaced at intervals of about each six exposures along it. To be of value, the Shoran flights at each end of the area must be positioned far enough inside the boundaries of the existing coverage to assure stereoscopic recovery of the pass points that will be selected for control. It is also important that forward overlaps in the cross flights be between fifty-three and sixty percent. If multiplex compilation methods are contemplated and if insufficient orientation data are vailable,

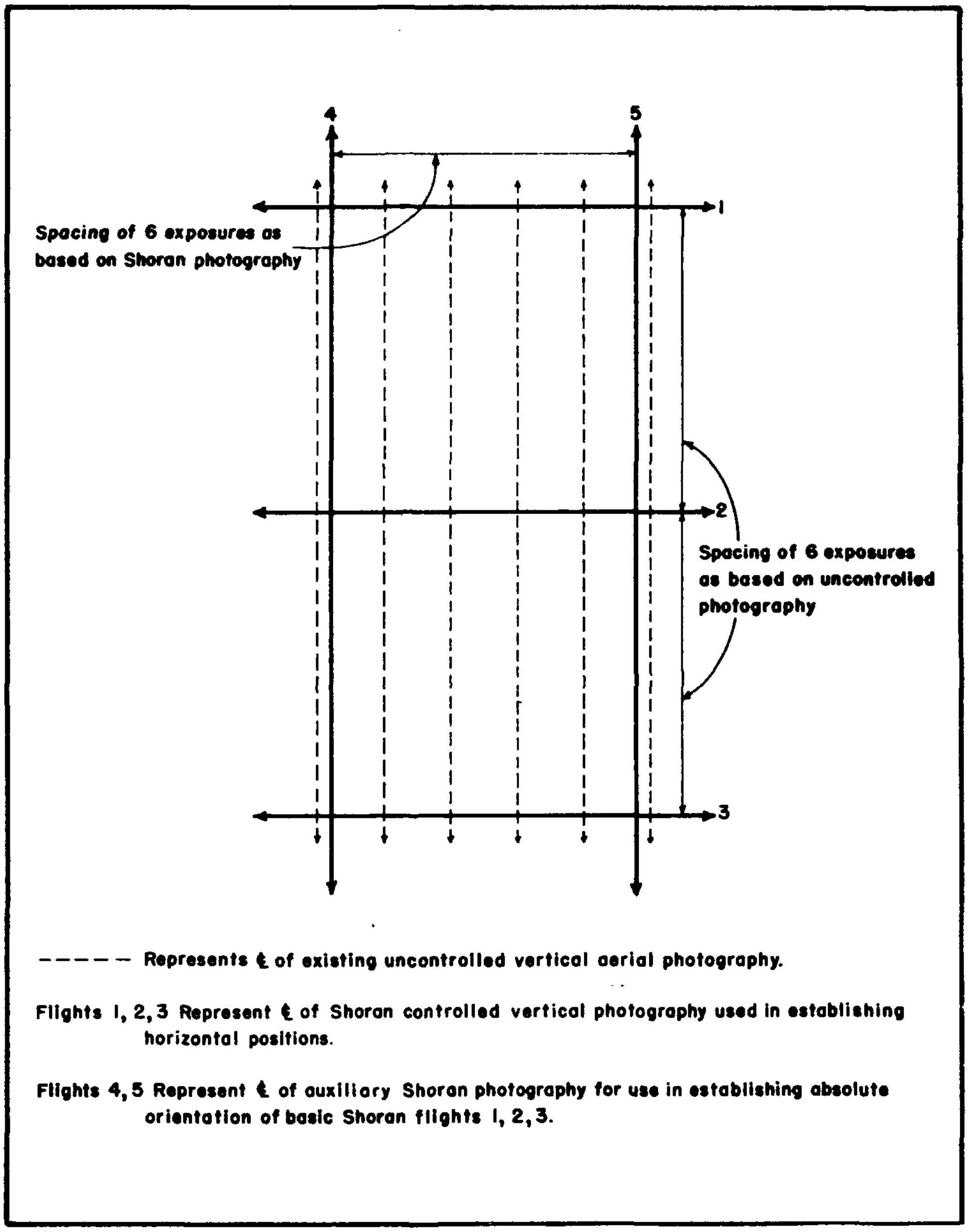


FIG. 4-4. FLIGHT PLAN FOR USE IN APPLYING SHORAN TO AREAS WHERE UNCONTROLLED PHOTOGRAPHY IS AVAILABLE AND WHERE VERTICAL CONTROL IS LIMITED.

auxiliary flights at right angles to the basic Shoran flights (parallel to the uncontrolled flights) will be required to establish orientation. Fig. 4-4 illustrates the proper layout of such a plan. While the auxiliary flights must be unbroken for about three exposures on each side of the basic control flights (1, 2, and 3 of Fig. 4-4) it is not necessary that they be continuous throughout their entire length. The auxiliaries will not be needed at all if sufficient vertical control is available or if the existing photography is accompanied with good altimeter readings which will permit tilt recovery at right angles to the control flights. Shoran cross flight photography should be used only with uncontrolled photography which meets specifications for good mapping coverage. It is especially important that the existing flights be free of breaks that would prohibit bridging between the control strips.

7. Requests for Velocity Corrections. Where a very high degree of accuracy in positioning the photography with respect to Shoran ground stations is required, velocity corrections as computed from meteorological conditions at the time of operations must be requested in the specifications for photography. Velocity tables included in this manual list the necessary corrections as based on "average" conditions in the United States at about 40° latitude. Distance errors introduced by use of these tables will amount to no more than about 1 part in 20,000 for Shoran missions anywhere in this country, even with maximum deviation from an average atmosphere. When Shoran is being used in other parts of the world, it may be necessary to consider these errors. Consultation with Air Force meteorologists usually will reveal the possible effects on distance measurements at the time and place of the proposed operations. Since several methods for observing atmospheric conditions are available to the photographic units, only the accuracy required in the velocity corrections should be stated in the photographic specifications.

8. Installation of Aerial Camera. If the aerial camera is located in the aircraft at any position other than half-way between the Shoran antennas, an otherwise unnecessary correction must be applied during later position computations. The required correction is equal to the displacement of the camera from the mid-point and it must be applied in a direction that is dependent upon the heading of the aircraft at the instant of each exposure. Requests for photography should stress the need for camera installation within at least a foot or two of the optimum position, if at all possible.

9. Specifications for Photography. The specifications for Shoran photographic operations are best worked out in cooperation with the Air Force unit which is to do the flying. Complete coordination by means of constant liaison is required to assure maximum utilization of the control data. Requests for photography should

include the following information (as requirements concerning aerial photography will vary with the mission at hand, the list is not necessarily complete in this respect). Notes in the margin refer to chapter and paragraph numbers where detailed discussions may be found.

a. An outline of the area to be photographed on the best available map, in triplicate.

b. Type of mapping camera to be used. IV - 2

c. Required photo scale or flying height, with allowable tolerance. IV - 1

d. Required forward and side overlap. IV - 1

e. Maximum allowable tilt and crab. IV - 4

f. Aerial and recorder film required.

g. Number and kind of prints desired.

h. Period during which work is to be performed.

i. An indication of existing ground control and desired sites for Shoran ground stations. III - 2

j. Accuracy required in locating and referencing Shoran ground control stations. III - 2

k. Whether or not base line length is to be established by the Shoran line-crossing method. I - 8

l. Requirement for synchronizing exposures of all aerial and recording cameras. II - 5

m. Requirement for installing aerial camera relative to transmitting and receiving antennas so that no error results, or for supplying a correction factor. IV - 8

n. Request for the following data:

(1) A statement as to which ground station each of the mileage counters refer. II - 3

(2) Delay of each ground station (G_d). II - 5

(3) Airborne timing oscillator frequency (F). II - 5

(4) Airborne zero readings (R_z) at start of each mission or when operators are changed during a mission. II - 5

(5) Chart or table of velocity corrections (V), if applicable. II - 6

(6) Chart or table of timing non-linearity corrections (C_T). II - 5

(7) Corrections for separation of airborne transmitting and receiving antennas (C_{AA}). II - 5

(8) Manual readings of distance counters at instant of one exposure near the beginning and the end of each mission. IV - 3

(9) Correction for installation of aerial camera (D), if applicable. IV - 8

(10) Information needed for correlating aerial and recording camera exposure numbers. IV - 3

(11) True flying heights (H), if applicable. VI - 1

(12) A Shoran operational log reporting operational details of the camera, recorders, and airborne Shoran set.

(13) Exact aerial camera focal length and frame dimensions between opposite fiducial marks. IV - 2

o. Any other facts pertinent to mission.

A liaison officer from the Corps of Engineers should be available to the Air Force organization to follow the progress of the aerial photography and to explain the photographic requirements to the Air Force unit, if necessary. A liaison officer from the Air Force organization accomplishing the photography should be available to the topographic unit from the delivery of the film through the planimetric compilation stage to explain Shoran data and photography, if necessary.

A typical set of specifications for Shoran-controlled area coverage photography is included in Appendix B. It represents the type of work that can be requested under peacetime conditions, in areas where adequate ground sites are available, and where optimum operating efficiency can be maintained.

10. Indexing. Proper indexing of the aerial and Shoran recorder film is extremely important. The information appearing on the data cards of both the mapping and the recorder cameras must be sufficiently detailed to permit positive cross reference, and any data noted by the cameraman and the Shoran operator should be kept with the film as an aid to later mapping operations. After the negatives have been processed, much of the information gathered by the cameraman is inked upon each end of the film rolls by the Air Force photographic laboratory as a permanent record. Details of these film titles are prescribed in FM 21-25 and in Air Force regulations. As a safeguard against separation, the 35-mm recorder film should be wrapped around its corresponding aerial film roll so that both will be filed in the same container.

Upon receipt of the quick prints by the Engineer topographic unit, an index of the aerial photography is prepared. This is best prepared by assembling a rough shingle mosaic with prints trimmed to image edge on three sides but maintaining the recorded data where a T-5 or similar camera was used. In area coverage missions with auxiliary cross flights, it is better to indicate the approximate centers of the cross flight prints by prominent circles or crosses since the use of the actual photographs would confuse or cover information needed later in the map compilation stage. Large, easily read numbers are placed on each print, the appropriate title information is placed adjacent to the assembly, and the entire index is photographically reduced to a convenient size. Prints made from the negative will serve for practically any purpose. Latitude and longitude lines are usually drawn on some of the prints after the coordinates of a few well-placed photographs have been computed.

CHAPTER V

COMPUTATIONS

CHAPTER V

COMPUTATIONS

1. General. Mapping with Shoran-controlled aerial photography requires a number of computational steps in the conversion from basic distance readings to usable map coordinates. Printed forms are provided to insure efficiency and consistency of method. Mileage counter readings are first corrected for instrument calibration errors and then reduced to geodetic distances through the use of ground station elevations and the best available value for aircraft flying height. Next, the reduced distances, together with the length of the Shoran base line, are used in computing the position of each Shoran point. In the usual case where positions of ground stations are known, coordinates of each point are computed on the standard Universal Transverse Mercator grid. However, this chapter also includes an explanation of the special Shoran grid for use in areas where the absolute location of the ground sites has not been established.

The various computation forms covered in this chapter, together with a short explanation of the way in which each one fits into the Shoran mapping procedure, are as follows:

Shoran Form No.	Title	Use
1	Inverse Computation, UTM Grid	Establishes length of Shoran base line between points of known coordinates.
2	Shoran Reduction Correction, C_1	Provides major correction in reducing from Shoran readings to geodetic distances.
3	Shoran Reduction	Completes the reduction to geodetic distance.
4	Computation of Coefficients	Master sheet for use with Form 5. (Only one computation needed for each pair of Shoran ground stations.)
5	UTM Position from Reduced Shoran Distances	Provides UTM coordinates for plotting of Shoran points.
6	Shoran Grid Coordinates	Provides coordinates for plotting on Shoran grid.

Shoran Form No.	Title	Use
AMS Form No. 3-134	Universal Transverse Mercator Grid Coordinates	Converts from geographic to UTM grid coordinates.
AMS Form No. 3-141	Geographic Coordinates from UTM Grid Coordinates	Converts from UTM to geographic coordinates.

The conversions between UTM and geographic position, which are performed on standard Army Map Service forms, are not peculiar to Shoran mapping but an explanation of their solutions may not, as yet, be readily available in other publications. The last paragraph of this chapter covers the computations involved in adding a geographic graticule to maps that were originally compiled on the Shoran grid. This necessity might arise if Shoran ground stations were tied into a triangulation network at some time after mapping operations were begun. A supply of printed forms will not be needed in this latter case because of the infrequency with which solutions are required.

Computations should be performed by the methods presented herein. Form No. 5 is self-checking; all other work must be thoroughly checked to avoid possible time-consuming delays in later steps of map compilation. Although each form is straightforward, the illustrated examples should be followed until proficiency is gained. Work is designed for solution on calculating machines having 8- or 10-digit keyboards and, where trigonometric functions are required, 7-place natural tables may be used. Tables peculiar to Shoran computations and those not readily available to topographic units are included in Appendix C. All other tables, including those required for UTM grid computations, can be obtained from the Army Map Service. Requests for these data must include a designation as to the reference spheroid for which tabulations are desired.

2. Inverse Computation. The first step in the computations will be to determine accurately the distance between the two Shoran ground stations. This distance is obtained by means of the inverse or back computation if the horizontal position of each ground station is known. Where the ground antennas were placed exactly over triangulation stations, the coordinates may be taken from existing trig lists. Otherwise, positions must be determined from survey notes supplied by the photographic unit. The required distance computation is performed on Shoran Form 1, Inverse Computation, Universal Transverse Mercator Grid (Fig. 5-1), and although the form is self-explanatory, the following points will prove helpful:

SHORAN FORM NO. 1

INVERSE COMPUTATION
UNIVERSAL TRANSVERSE MERCATOR GRID

STA. A *Cheyenne, Wyoming* STA. B *Imperial, Nebraska* SPHEROID *Clarke, 1866*

N_A = 4,558,667.73 E_A = 514,712.24

N_B = 4,489,917.42 E_B = 785,734.42

$\Delta N=(N_A-N_B)$ = 68,750.31 $\Delta E=(E_A-E_B)$ = − 271,022.18

$N_{AB}=\frac{1}{2}(N_A+N_B)$ = 4,524,292.575 $E_{AB}=\frac{1}{2}(E_A+E_B)$ = 650,223.330

$W'=\sqrt{(\Delta N)^2+(\Delta E)^2}$ = 279,606.200

$$q=(1\times10^{-6})(E-500{,}000)$$

$$k=.9996(1+\boxed{\mathrm{XVIII}}\,q^2+[3\times10^{-5}]q^4)$$

$\underline{\boxed{\mathrm{XVIII}}}$ from AMS TM, <u>UTM Grid Tables for Latitude 0°–80°</u>

	q	q^2	q^4	$\boxed{\mathrm{XVIII}}$	$\boxed{\mathrm{XVIII}}q^2$	$(3\times10^{-5})q^4$	k	$\frac{1}{k}$
A	.01471224	.00021645	.00000006	.012312	.00000266	0	.99960266	1.00039749
B	.28573442	.08164415	.00666577	.012313	.00100528	.00000020	1.00060508	.99939529
AB	.15022333	.02256705	.00050927	.012313	.00027787	.00000002	.99987778	1.00012223

$$\frac{1}{K_{AB}}=\frac{1}{6}\left(\frac{1}{k_A}+\frac{4}{k_{AB}}+\frac{1}{k_B}\right)=1.000046351$$

$$W=W'\left(\frac{1}{K_{AB}}\right)=279{,}619.3 \text{ Meters}$$

COMPUTED BY *A.H.F.* DATE *9 Mar. 1950* CHECKED BY *C.C.L.* DATE *9 Mar. 1950*

FIG. 5-1. INVERSE COMPUTATION, UTM COORDINATES.

(1) The westernmost ground station is always designated Station A.

(2) Subscript AB denotes the mid-point of the line AB.

(3) N and E designate northing and easting coordinates on the UTM grid, N_A is the northing of point A; E_B is the easting of point B, and the like.

(4) Values of the quantity, XVIII, are obtained from Army Map Service technical manuals, UTM Grid Tables for Latitude 0°-80°. They are dependent upon the northing of the point and the spheroid to which the published map is to be referred.

When the horizontal positions of the ground stations are given as geographic coordinates, they must be converted to UTM coordinates before making the inverse computation. The solution is made on Army Map Service Form No. 3-134 (Fig. 5-2). A detailed account of the computational procedure is given in AMS TM No. 19, Universal Transverse Mercator Grid, currently being rewritten as an Army Field Manual.

In Shoran-controlled mapping operations such great distances are covered that it is possible for the ground stations to be situated in different grid zones, or for the ground stations to be in one zone and the area being mapped to be in another. Where points are so located, their positions should first be transformed to coordinates of the zone containing the area that is to be mapped. The aforementioned AMS technical manual discusses the procedure for making this conversion.

3. The Shoran Reduction Formulas. Shoran dial readings obtained from the recorder film must be corrected for instrumental and propagation errors, and then be reduced to map distances, before the map coordinates can be determined. The necessary formulas are given below:

$$M = S - C_1 + C_T - \Delta M$$

$$C_1 = 1 + 2 + 3 + 4 + 5 + 6 - 7 - 8 - 9$$

$$\Delta M = \left[2.3920\, S(10^{-4}) + \frac{3.5870(H-K)}{S} + \frac{6.4332(H-K)^3}{S^3}\right] \Delta H$$

where M = Ground or geodetic distance in miles
S = Uncorrected Shoran distance reading in miles

UNIVERSAL TRANSVERSE MERCATOR GRID COORDINATES

Station *Ground Station A* Location *Cheyenne, Wyoming*

Zone *13* Spheroid *Clarke, 1866* Unit *Shoran Section*

	°	'	"				°	'	"
Latitude, Φ	41	10	52.087	p	.0631478	Longitude, λ	104	49	28.522
Tabular (IV) (Even minute of Φ)	233	032	195	p^2	.00398764	Central Meridian, λ_0	105°	00'	00.000"
Interpolation for seconds of Φ	–	51	267	p^3	.00025181	Δλ	0°	10'	31.478"
Δ^2(IV) from graph			001	p^4	.00001590				

	(IV)	232	980	929
Tabular (V) (Even minute of Φ)			12	379
Interpolation for seconds of Φ		–		048
	(V)		12	331
	(IV)p	14	712	233
	$(V)p^3$			003
From graph	B_5			000
+ East / – West of Central Meridian	E'	14	712	24
False Easting	FE	500	000	00
	E	514	712	24

Tabular (I) (Even minute of Φ)				4557	046	722
Interpolation for seconds of Φ				1	606	177
			(I)	4558	652	899
Tabular (II) (Even minute of Φ)	3718	371				
Interpolation for seconds of Φ		255				
(II)	3718	626	$(II)p^2$		14	829
(III)	1	761	$(III)p^4$			000
From graph			A_6			000
			N	4558	667	73

Date Computed: *28 Mar. 1950* By: *A.H.F.* Checked by: *C.C.L.*

ARMY MAP SERVICE
CORPS OF ENGINEERS, U. S. ARMY 204345

FORM NO. 3-134

FIG. 5-2. UNIVERSAL TRANSVERSE MERCATOR COORDINATES.

C_T = Timing non-linearity correction in miles

ΔM = Differential distance correction (in miles) resulting from flying height deviations of individual exposures from the mean of the mission

C_1 = Correction (in miles) composed of the following terms:

$$1 = 2.3920\ S(H + K)\ 10^{-4}$$

$$2 = \frac{1.7935(H - K)^2}{S}$$

$$3 = \frac{1.6083(H - K)^4}{S^3}$$

$$4 = V_3$$

$$5 = \frac{F - 93{,}109.5}{F} \cdot S$$

$6 = G_d + R_Z + C_{AA} - 100.0000$ = Constant term consisting of corrections for ground station delay $[+ (G_d - .1800)]$, airborne zeroing $[- (99.8200 - R_Z)]$, and separation of airborne antennas $[+C_{AA}]$

$$7 = .24848 \; S^3 \; (10^{-8})$$

$$8 = (V_1 - V_2) \; S \; (10^{-4})$$

9 = Correction for assumption that the Shoran ray path has a constant radius, regardless of its height above sea level.

H = Corrected mean flying height above sea level, expressed in 10,000-foot units

K = Elevation of ground station antenna above sea level, expressed in 10,000-foot units

ΔH = Deviation of individual flying heights from the mean, expressed in 10,000-foot units

F = Actual timing frequency in cycles per second

V_1, V_2, and V_3 = terms of velocity correction, in miles

G_d = Ground station delay, in miles

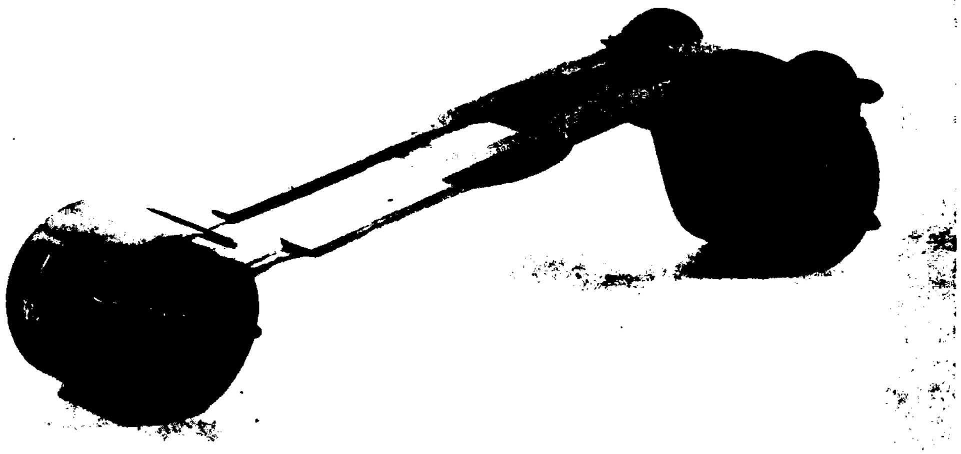
R_z = Observed zero of airborne set, in miles

C_{AA} = Correction for separation of airborne antennas, in miles

These formulas are identical to those presented in Chapter II, par. 7, but here the expressions have been further expanded and insignificant terms have been eliminated to permit greater ease in computation. It will be noted that terms 1, 2, 3, and 7 of the expression just given correspond to the first four terms of the equation of Chapter II; the velocity correction (V of the Chapter II expression) is made up of terms 4 and 8; the calibration corrections (C of Chapter II) are covered by terms C_T, 5 and 6; and term 9 is equivalent to B in the original equation.

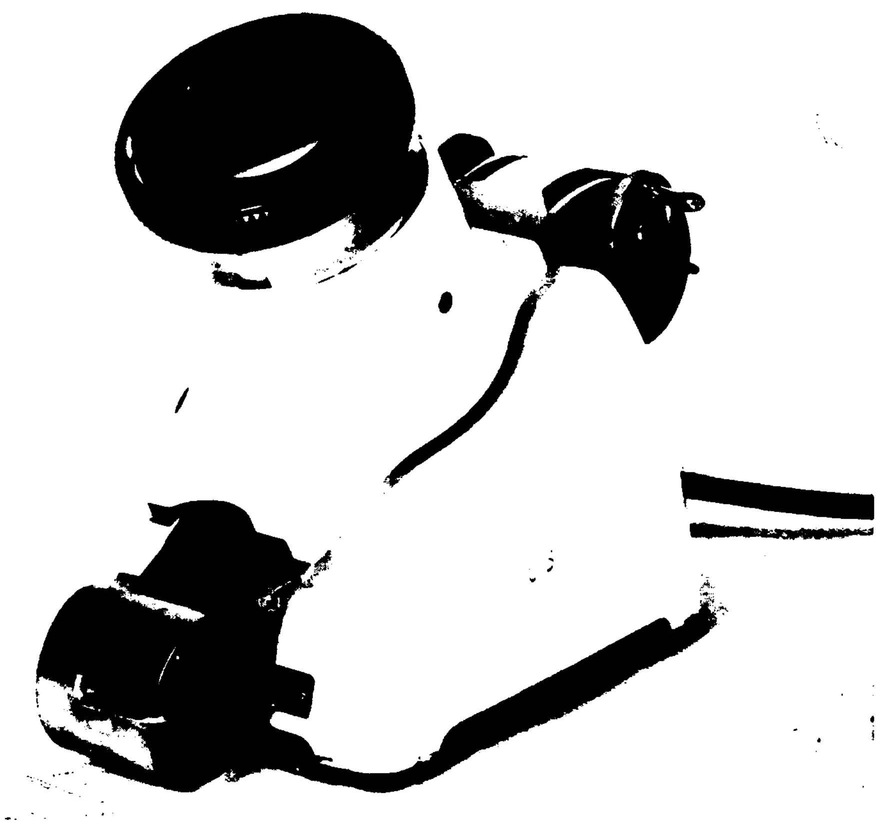
Nearly all of the unknown quantities in the reduction formulas will be furnished by the Air Force photographic unit as called for in the specifications for photography. The ground station delay (G_d), timing frequency (F), observed zero (R_z), and corrections for separation of airborne antennas (C_{AA}) are all constant for any one mission. Timing non-linearity corrections (C_T) will be furnished in the form of tables or curves. If velocity corrections have been requested, they will be supplied in the form of tables or curves based on atmospheric conditions at the time of photography. The values then will replace terms 4 and 8 of the reduction equation. If standard atmospheric conditions are to be assumed, corrections are taken from Tables I, II, and III of Appendix C. Term 9 is set forth in Table IV of Appendix C.

The true mean flying height (H) either must be determined by the photogrammetric method of Chapter VI, or must be supplied by the photographic unit. Differential flying heights (ΔH) are



159-4-114

FIG. 5-3. FILM HOLDER FOR SHORAN FILM VIEWER.



159-4-116

FIG. 5-4. SHORAN FILM VIEWER WITH FILM HOLDER.

established from the altimeter readings. The required ground station height (K) can be taken from trig lists if the antenna was placed over an existing station; otherwise, it must be determined from survey notes. It should be noted that unless unusual field conditions were employed, 50 feet must be added to the ground elevation to account for the height of the antenna mast.

4. Tabulation of Recording Film Data. Distance readings from the aircraft to the ground stations at the instant of each aerial exposure are contained on the film of the 35-mm Shoran recording camera. Barometric altimeter readings are obtained from the altimeter recording film if available; otherwise, values are taken from the Shoran recorder. The viewer shown in Figs. 5-3 and 5-4 is used in reading the necessary values directly from the recording film negatives. The viewer is essentially a magnifying glass to which has been added a film holder and a light source of variable intensity. To facilitate the placement and removal of the film holder from the viewer itself, the bottom cover of the viewer is taken off and the screw which forms the stop is removed from the condensing lens pivot. This permits the condensing lens to be rotated through 360°. It will also be helpful to remove permanently the black metal masking screen that is located on the under side of the lens. During tabulation of the recorded data, maximum efficiency is achieved if one person makes the necessary readings and another records them. Upon completion of the listing, the operators exchange places and all values are reread as a check.

Standard Corps of Engineers nomenclature for the viewer is "Film Viewer, 35 mm film strip, for vertical or horizontal transparencies, without film holder, with case, Leitz model B or equal." Standard nomenclature for the holder is "Film Holder, 35 mm film strip, winding, for Leitz model B desk viewer."

Occasionally, simultaneous exposures of the aerial, Shoran, and altimeter film will not carry the same numbers and so correlation will be difficult. Often, this problem will have been caught and straightened out before receipt of the film by the mapping unit. However, the possibility of mistakes, or at least of confusion, from this source should be recognized and a quick check should be made by comparing numbers at the start and finish of each flight. Should trouble appear, correlation usually can be established by checking the time intervals on the clocks that show in all three recording films.

The first tabulation will be that of flying height as indicated by the altimeter readings appearing either on the Shoran or separate altimeter recorder film. No special form is used for this listing. Values to the nearest 20 feet are tabulated opposite the exposure number of each photograph to be used in the map compilation.

SHORAN FORM NO. 2

SHORAN REDUCTION CORRECTION C_1

MISSION *Rocky Mts. Colo.*

DATE *16 April 1949* SHEET *1* OF *1*

GROUND STATION *Cheyenne, Wyoming*

ELEV. OF GROUND STATION (K) = *6,313* FT.

MEAN FLYING HEIGHT (H) = *25,600* FT.

(H+K) IN 10,000 FT. UNITS *3.1913*   (H−K) IN 10,000 FT. UNITS *1.9287*

ACTUAL TIMMING FREQUENCY (F) = *93,113.0* CPS   GROUND STATION DELAY (G_d) = *.1940* MI.

OBSERVED ZERO OF AIRBORNE SET (R_Z) = *99.820* MI.

CORRECTION FOR SEPARATION OF AIRBORNE ANTENNAE (C_{AA}) = *0* MI.

$$C_1 = 1 + 2 + 3 + 4 + 5 + 6 - 7 - 8 - 9$$

$1 = 2.3920\,(H+K)\,S\,(10^{-4}) =$ *.00076336* S

$2 = \dfrac{1.7935\,(H-K)^2}{S} =$ *$\dfrac{6.671611}{S}$*

$3 = \dfrac{1.6083\,(H-K)^4}{S^3} =$ *$\dfrac{22.254907}{S^3}$*

$4 =$ V_3 FROM TABLE NO. III

$5 = \dfrac{F - 93{,}109.5}{F}\,S =$ *+ .00003759* S

$6 = G_d + R_Z + C_{AA} - 100.0000 =$ *+ .0140* MI.

$7 = .24848\,S^3\,(10^{-8})$

$8 = (V_1 - V_2)\,S\,(10^{-4}) =$ *.00010064* S

9 = FROM TABLE NO. IV

S = SHORAN DISTANCE

V_1 FROM TABLE NO. I ; V_2 FROM TABLE NO. II

S	1	2	3	4	5	6	7	8	9	C_1
100	.0763	.0667	.0000	.0007	+.0038	+.0140	.0025	.0101	.0000	.1489
105	.0802	.0635	–	.0008	.0039	.0140	.0029	.0106	–	.1489
110	.0840	.0607	–	.0009	.0041	.0140	.0033	.0111	–	.1493
115	.0878	.0580	–	.0010	.0043	.0140	.0038	.0116	–	.1497
120	.0916	.0556	–	.0012	.0045	.0140	.0043	.0121	–	.1505
125	.0954	.0634	–	.0013	.0047	.0140	.0049	.0126	–	.1513

LIMITING VALUES	C_1
FROM 100 TO 105.5	.1488
105.5 TO 108	.1490
108 TO 110.5	.1492
110.5 TO 112.75	.1494
112.75 TO 114.75	.1496
114.75 TO 116	.1498
116 TO 117.75	.1500
117.75 TO 119	.1502
119 TO 120.25	.1504
120.25 TO 121.5	.1506
121.5 TO 123	.1508
123 TO 124	.1510
124 TO 125	.1512

COMPUTED BY *A.H.F.*   DATE *3 March 1950*

CHECKED BY *C.C.L.*   DATE *3 March 1950*

FIG. 5-5. SHORAN REDUCTION CORRECTION C_1.

Flying heights for different missions are tabulated separately, since varying meteorological conditions between missions could cause the average reading to differ considerably, even though the actual exposure heights were the same. (One mission is considered to be a group of exposures that were taken consecutively from the same aircraft over one area and on the same day.) The mean altimeter reading of the mission is next computed and its value is recorded. A discussion of methods for converting from barometric to true flying heights is given in Chapter VI. Once established, the value is listed in the upper part of Shoran Form 2 (Fig. 5-5).

This listing of altimeter readings also indicates the magnitude of the individual flying height deviations. Exposures that deviate from the mean by more than 100 feet are noted, and the amount and sign of the deviation is determined by subtracting the mean value from the individual readings. Variations to the nearest 100 feet and expressed in 10,000-foot units are tabulated on Shoran Form 3 in the columns headed ΔM, using the upper half of the blocks as shown in Fig. 5-7. Since flying height differences affect the distance from each ground station to the aircraft, the deviations must be entered in both ΔM columns. The tabulation of mileage counter readings to the nearest .001 mile is also made on Shoran Form 3 under the columns headed "Shoran Reading." Information received with the photography must indicate the ground stations to which the readings refer.

5. Determination of Reduction Correction, C_1. The C_1 term of the reduction equation is computed on Shoran Form 2 (Fig. 5-5). A separate sheet is used for distances from each ground site. Space is provided at the top of the form for the name of the ground station, mission number, and the tabulation of all calibration and other constants needed in the computation. The value entered for mean flying height must be the true value as determined by one of the methods of Chapter VI. The ground station elevation represents the height of the antenna which, in most operations, is on a mast 50 feet above the ground level. During the machine computations, maximum efficiency is attained by [illegible]ing in each column completely before passing on to the next ter[illegible]

It is not necessary to compute correction C_1 for each Shoran reading; instead, an equally accurate but more rapid method is used. The minimum and maximum dial readings from the aircraft to one of the ground stations are obtained from an examination of the tabulation on Form 3. Corrections are then computed to four decimal places at 5-mile intervals, starting at the even 5-mile value below the minimum reading and extending to the 5-mile value beyond the maximum reading. C_1 corrections thus obtained are plotted against distance on graph paper and a smooth curve is drawn through the points (Fig. 5-6). The scale of the graph should be such that corrections can be plotted directly to .0002 mile, and distances can be read to the nearest mile. Corrections for individual Shoran distance readings are then obtained from this curve to four decimal places and are entered in the appropriate column of Form 3. The determination of C_1 for distances measured from the other ground station is identical, but it is performed separately.

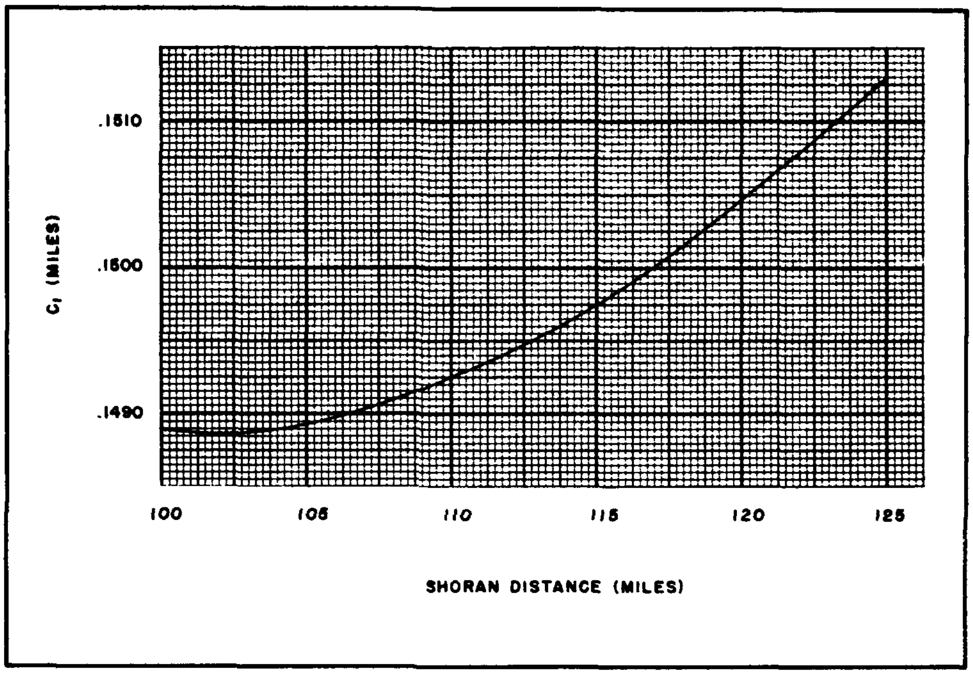


FIG. 5-6. TYPICAL C_1 CORRECTION CURVE.

Since the correction does not change very rapidly, the curve is usually rather flat; as a consequence, it may sometimes be advantageous to record the corrections to the nearest .0002 mile and then determine the limiting distance values of each. Space is provided on Form 2 for such a tabulation.

The determination of correction C_1 at 5-mile intervals will usually be sufficient. However, when the difference between any two successive corrections, as computed above, is greater than .010 mile, one or more intermediate points must be determined. Occasionally, it may even be necessary to compute the correction at 1-mile intervals over short distances in order to meet this restriction.

When the correction curve is too large for one sheet of paper, it should be broken into segments containing at least five computed points and plotted on separate sheets. Graph paper having

20 graduations per inch is preferred to larger scales, as it produces a more compact curve.

6. Velocity Correction. The Shoran velocity correction in the reduction formula is comprised of three terms, V_1, V_2, and V_3, for which tables based on the N.A.C.A. moist atmosphere are given in Appendix C. Because of varying atmospheric conditions, however, the use of such standard tables may introduce errors of as much as 1 part in 20,000 in Shoran distance measurements. Where greater accuracy is required, velocity corrections determined from meteorological soundings at the time of photography must be requested from the Air Force photographic unit. If the total velocity correction is furnished in the form of a graph, the values taken from the curve should be entered in column 8 of Shoran Form 2 and algebraically added to the other terms. Column 4 (V_3) is then left blank.

7. Geodetic Distances from Shoran Readings. The reduction from Shoran to true ground distance is determined by the formula:

$$M = S - C_1 + C_T - \Delta M$$

The necessary computations are performed on Shoran Form 3 (Fig. 5-7). Space is provided at the top of the form for noting the controlling ground stations and the mission data. First, the exposure numbers are listed in the left-hand column. Next, the Shoran readings and C_1 corrections for distances from both ground stations are tabulated in appropriate columns on both halves of the form (paragraph 4). Timing non-linearity corrections are taken from curves or tables that were worked up from calibration data and supplied with the photography. Term ΔM, the correction for the deviation of individual flying heights from the mean, need be computed only when deviations of 100 feet or more are encountered. The necessity for computing this term will occur so seldom under normal conditions of peacetime flying that no space is allotted for its solution. The necessary fomula is shown at the top of the form. When the corrections are required, computations are performed on a separate sheet and only the answers are tabulated in the lower half of the blocks on Form 3. The final step converts the reduced distances to meters to conform with later grid requirements in metric units.

8. UTM Positions from Reduced Shoran Distances. The computation of UTM grid coordinates is performed on Shoran Forms 4 and 5. Form 4 establishes a set of coefficients that are constant for any given pair of ground stations. Consequently, the computation need be made only once for any area controlled by the same two ground sites. Form 5 is used for the actual determination of coordinates.

SHORAN FORM NO. 3

REDUCTION FROM SHORAN TO GEODETIC DISTANCES

MISSION *Rocky Mts. Colo.*

GROUND STATION A (Westernmost) *Cheyenne, Wyo.*

GROUND STATION B (Easternmost) *Imperial, Neb.*

DATE *16 April 1949* SHEET *1* OF *1*

M = GROUND DISTANCE = $S - C_1 + C_T - \Delta M$

C_1 = REDUCTION TERM FROM SHORAN FORM 2 CORRECTION CURVE

C_T = TIMING NON-LINEARITY CORRECTION

S = SHORAN READING

$$\Delta M = \left[2.3920\, S(10^{-4}) + \frac{3.5870(H-K)}{S} + \frac{6.4332(H-K)^3}{S^3} \right] \Delta H$$

1 MILE = 1609.347 METERS

ΔM = CORRECTION FOR DEVIATION FROM MEAN FLYING HEIGHT

ΔH = DIFFERENTIAL FLYING HEIGHT IN 10,000 FT. UNITS (TRUE MEAN)

EXP. NO.	FROM GROUND STATION A						FROM GROUND STATION B					
	SHORAN READING	C_1	C_T	ΔM	GROUND DISTANCE MILES	GROUND DISTANCE METERS (M.)	SHORAN READING	C_1	C_T	ΔM	GROUND DISTANCE MILES	GROUND DISTANCE METERS (M.)
30	100.011	.1489	+.0027		99.8648	160,717.1	168.034	.1390	+.0036		167.8986	270,207.4
31	102.095	.1489	+.0043	+.0100 −.0010	101.9494	164,072.0	168.926	.1390	+.0037	+.0100 −.0013	168.7904	271,680.1
32	104.177	.1489	+.0045		104.0326	167,434.6	169.894	.1392	+.0030		169.7578	273,199.2

COMPUTED BY *C.C.L.* DATE *3 March 1950* CHECKED BY *A.H.F.* DATE *3 March 1950*

FIG. 5-7. REDUCTION FROM SHORAN TO GEODETIC DISTANCES.

a. A worked example of the master computation, Form 4, is shown in Fig. 5-8. During its solution the following points should be noted:

(1) Terms XVIII and I are taken from standard UTM grid tables. The particular tables employed must list values for the reference spheroid that has been designated for use in the area being mapped.

(2) The solution should always be performed by at least two separate operators so as to guard against carrying errors into later computations.

b. Fig. 5-9 illustrates the solution of Form 5. The top row provides space for listing the numbers, or other designations, of the points for which coordinates are desired. The reduced Shoran distances from each of the ground stations (M_1 and M_2) are taken from Form 3 and multiplied by the constant $.9996 \times 10^{-6}$ before entering the values as steps (1) and (2) on the form. Subsequent steps are indicated in the second column. For example, in step (3), the quantity tabulated for step (1) is first multiplied by the coefficient a_o from Form 4 and this product then is multiplied by the number 2. It should be noted that steps (9) and (10) require the selection of signs which depend upon the location of the points with respect to the Shoran base line. Both of these signs will remain constant throughout any one mission and so the two that are not to be used can be crossed out before work is begun.

Lines (17) and (18) supply the ground position of the point on the airplane that is halfway between the airborne antennas. On most aircraft the aerial camera will have been installed very near this mid-point (Chapter IV, par. 8) and so these values represent the final coordinates. Occasionally, however, the camera location will be such as to require a displacement correction and steps (19) through (22) will have to be filled in. The necessary computations are explained in paragraph 9.

Steps (23) through (30) provide a check for the computations. If lines (29) and (30) fail to agree to within about 1 meter, the work must be re-examined to locate the error. It is well to make the whole coordinate and check computation for the first point of each mission separately and completely before passing on to the remaining points. This assures that no gross errors will be made in the use of coefficients or placing of decimal points. After this, maximum efficiency is attained by computing each line all the way across the sheet before going to the next line.

SHORAN FORM NO 4

COEFFICIENTS
FOR USE WITH
COMPUTATION OF UTM POSITION
FROM
REDUCED SHORAN DISTANCES

MISSION *Rocky Mts. Colo.*

DATE *16 April 1949*

STA. A (Westernmost) *Cheyenne* STA. B (Easternmost) *Imperial* SPHERIOD *Clarke 1866*

N_B = *4,489,917.42* Meters E_B = *785,734.42* Meters

N_A = *4,558,667.73* Meters E_A = *514,712.24* Meters

$\frac{1}{2}(N_A+N_B)$ = *4,524,292.6* Meters W = *279,619.3* Meters

XVIII AND I FROM AMS TM, UTM GRID TABLES FOR LATITUDE 0° – 80°

(1)	$Y_B = N_B \cdot 10^{-6}$	4.489 917 4	(13)	$C_1 = (12)\cdot(8) + (11)\cdot(9)$	.969 321 6
(2)	$Y_A = N_A \cdot 10^{-6}$	4.558 667 7	(14)	$C_2 = (12)\cdot(9) - (11)\cdot(8)$	− .245 736 4
(3)	$X_B = (E_B - 500{,}000)\cdot 10^{-6}$	.285 734 4	(15)	XVIII for N_A	.012 312
(4)	$X_A = (E_A - 500{,}000)\cdot 10^{-6}$	.014 712 2	(16)	$K = \frac{6}{(15)}$	487. 329 4
(5)	$\Delta Y = (1) - (2)$	− .068 750 3	(17)	$F = \frac{2}{(16)}$	.004 104 0
(6)	$\Delta X = (3) - (4)$	.271 022 2	(18)	$C = 2 \cdot (17)$	.008 208 0
(7)	$\sqrt{(5)^2 + (6)^2}$	.279 606 2	(19)	$D = (15)\cdot(4)$	.000 181 1
(8)	$\frac{(6)}{(7)}$	.969 299 7	(20)	$B = 2 \cdot (19)$	.000 362 2
(9)	$\frac{(5)}{(7)}$	− .245 882 6	(21)	$(4)\cdot(19)$	.000 002 7
(10)	XVIII for $\frac{1}{2}(N_A+N_B)$	.012 313	(22)	$A = \frac{(21)^2}{6} + (21) + 1$	1.000 002 7
(11)	$\frac{[(3) + 2\cdot(4)]\cdot(5)\cdot(10)}{3}$	− .000 088 9	(23)	$a_0 = .9996 \cdot W \cdot 10^{-6}$	.279 507 5
(12)	$\frac{2 - (11)^2}{2}$	1.000 000 0			

COMPUTED BY *A.H.F.* CHECKED BY *C.C.L.*

DATE *5 March 1950* DATE *5 March 1950*

FIG. 5-8. COMPUTATION OF COEFFICIENTS - UTM POSITION FROM REDUCED SHORAN DISTANCES.

SHORAN FORM NO. 5

UTM POSITION FROM REDUCED SHORAN DISTANCES

M_1 = REDUCED SHORAN DISTANCE FROM GROUND STATION A (FROM SHORAN FORM 3)
M_2 = REDUCED SHORAN DISTANCE FROM GROUND STATION B (FROM SHORAN FORM 3)
VALUES OF C_1, C_2, k, A, B, C, D, F, a_0, X_A, X_B, Y_A, AND Y_B FROM SHORAN FORM 4
N_p AND E_p = COORDINATES OF POINT MIDWAY BETWEEN SHORAN ANTENNAE
ΔN AND ΔE = CAMERA DISPLACEMENT CORRECTIONS   N AND E = FINAL UTM COORDINATES $N = N_p + \Delta N$ $E = E_p + \Delta E$
ΔN AND ΔE ARE ZERO FOR MOST AERIAL CAMERA INSTALLATIONS

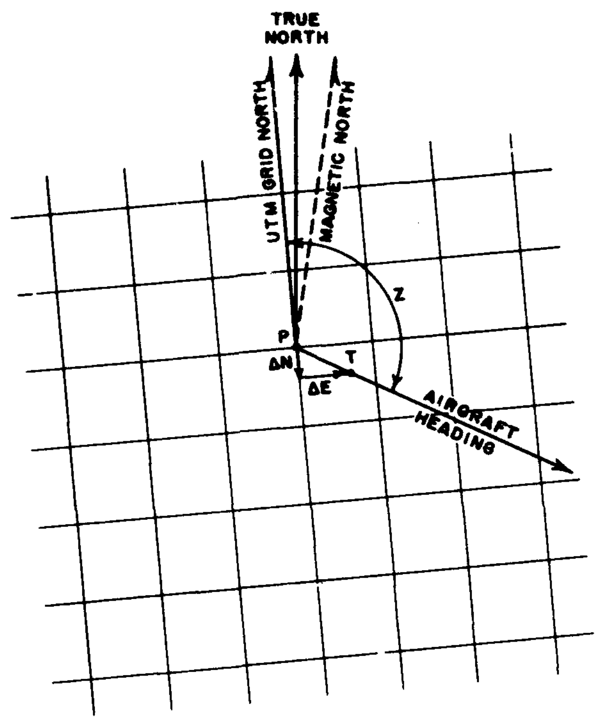
MISSION Rocky Mts, Colo.
DATE 16 April 1948 SHEET 1 OF 1
STATION A (Westernmost) Cheyenne, Wyo.
STATION B (Easternmost) Imperial, Neb.

POINT NUMBER		30	31						
(1)	$.9996\, M_1 \cdot 10^{-6}$	.160 652 8	.164 006 4						(1)
(2)	$.9996\, M_2 \cdot 10^{-6}$	.270 099 3	.271 530 4						(2)
(3)	$2 \cdot a_0 \cdot (1)$	.089 807 3	.091 682 0						(3)
(4)	$[a_0^2 + (1)^2 - (2)^2]\frac{1}{(3)}$	.344 962 3	.341 329 6						(4)
(5)	$\sqrt{1-(4)^2}$	.938 616 5	.939 943 7						(5)
(6)	$(3)\cdot(5)\cdot\frac{1}{k}$	.000 173 0	.000 176 8						(6)
(7)	$(5)+(6)\cdot(4)$	.938 676 2	.940 004 0						(7)
(8)	$(4)-(6)\cdot(5)$	.344 799 9	.341 163 4						(8)
(9)	$(8)\cdot C_1 \mp (7)\cdot C_2$ *	.103 498 8	.099 647 5						(9)
(10)	$(8)\cdot C_2 \pm (7)\cdot C_1$ *	-.994 629 7	-.996 022 9						(10)
(11)	$(1)\cdot(9)$	.016 627 4	.016 342 8						(11)
(12)	$(1)\cdot(10)$	-.159 790 0	-.163 190 1						(12)
(13)	$(11)^2$	.000 276 5	.000 267 1						(13)
(14)	$(13)-(12)^2$	-.025 256 3	-.026 363 9						(14)
(15)	$[A+(11)\cdot B+(13)\cdot C]\cdot(12)+Y_A$	4.398 875 9	4.395 475 6						(15)
(16)	$[(11)\cdot F+D]\cdot(14)+(11)\cdot A+X_A$	.031 333 3	.031 048 5						(16)
(17)	$N_p = (15)\cdot 10^6$	4,398,876	4,395,476						(17)
(18)	$E_p = (16)\cdot 10^6 + 500{,}000$	531,333	531,049						(18)
(19)	ΔN								(19)
(20)	ΔE								(20)
(21)	$N = (17)+(19)$								(21)
(22)	$E = (18)+(20)$								(22)
	CHECK COMPUTATION								
(23)	$X_B^2 + (16)\cdot X_B + (16)^2$	.091 578 9	.091 479 8						(23)
(24)	$\frac{1}{2}(N_B + N_p)$	4,444,000	4,443,000						(24)
(25)	XVIII for $\frac{1}{2}(N_B + N_p)$	.012 315	.012 315						(25)
(26)	$[(23)\cdot(25)]\cdot\frac{1}{3}+1$	1.000 375 9	1.000 375 5						(26)
(27)	$(15)-Y_B$	-.091 041 5	-.094 441 6						(27)
(28)	$(16)-X_B$	-.254 401 1	-.254 685 9						(28)
(29)	$\sqrt{(27)^2+(28)^2}\cdot 10^6$	270,200.8	271,632.3						(29)
(30)	$(2)\cdot(26)\cdot 10^6$	270,200.8	271,632.4						(30)

* Upper sign used if point is North of base line AB or its extension
Lower sign used if point is South of base line AB or its extension

COMPUTED BY A.H.F. DATE 5 March 1950
CHECKED BY C.C.L. DATE 6 March 1950

FIG. 5-9. UTM POSITION FROM REDUCED SHORAN DISTANCES.



P = POINT AT WHICH SHORAN POSITION IS EFFECTIVE

T = POSITION OF AERIAL CAMERA IN AIRCRAFT

D = PT = DISPLACEMENT OF CAMERA FROM POINT MIDWAY BETWEEN SHORAN ANTENNAE (SKETCH ILLUSTRATES FORWARD DISPLACEMENT)

Z = GRID AZIMUTH OF AIRCRAFT HEADING

$\Delta N = D \cos Z$ $\qquad$ $\Delta E = D \sin Z$

FIG. 5-10. DETERMINATION OF CORRECTION FOR CAMERA DISPLACEMENT.

9. Correction for Installation of Aerial Camera. Camera installation corrections need to be computed only when the displacement from the mid-point between airborne antennas is great enough to affect map accuracy. For instance, it would be a waste of time to consider a 2-foot displacement when computing coordinates for map control at a scale on which it was impossible to plot to any closer than about 10 feet. In most military mapping operations, corrections should be computed when the displacement is greater than 1 meter.

Fig. 5-10 illustrates the method to be used for determining the displacement correction. Once the mid-point position of the antennas has been determined, the camera coordinates are established by the formulas

$$N = N_p + \Delta N$$

$$E = E_p + \Delta E$$

where N_p and E_p = UTM coordinates of point midway between Shoran airborne antennas

$\Delta N = D \cos Z$

$\Delta E = D \sin Z$

D = Displacement of aerial camera from the mid-point of the antennas in meters

Z = Grid azimuth of aircraft heading

The quantity, D, is assumed to be positive when the camera is forward of the mid-point between antennas and negative when the camera is toward the tail of the aircraft. The grid azimuth, Z, is determined by correcting the compass heading, as read from the Shoran recording film, first for magnetic declination and then for convergence of the UTM grid.

Magnetic declination of the compass is determined from an isogonic chart. The convergence correction is dependent upon the mean latitude of the area being mapped (ϕ_m) and the distance, in degrees, from the center of the area to the central meridian of the grid zone. Values are listed in Fig. 5-11. In the Northern Hemisphere, convergence corrections are added to the compass readings if the area is west of the central meridian and subtracted if it is to the east; signs are reversed when working in the Southern Hemisphere. Mistakes introduced by the possible selection of wrong algebraic signs can be avoided if a diagram similar to that shown in Fig. 5-10 is drawn for each mission.

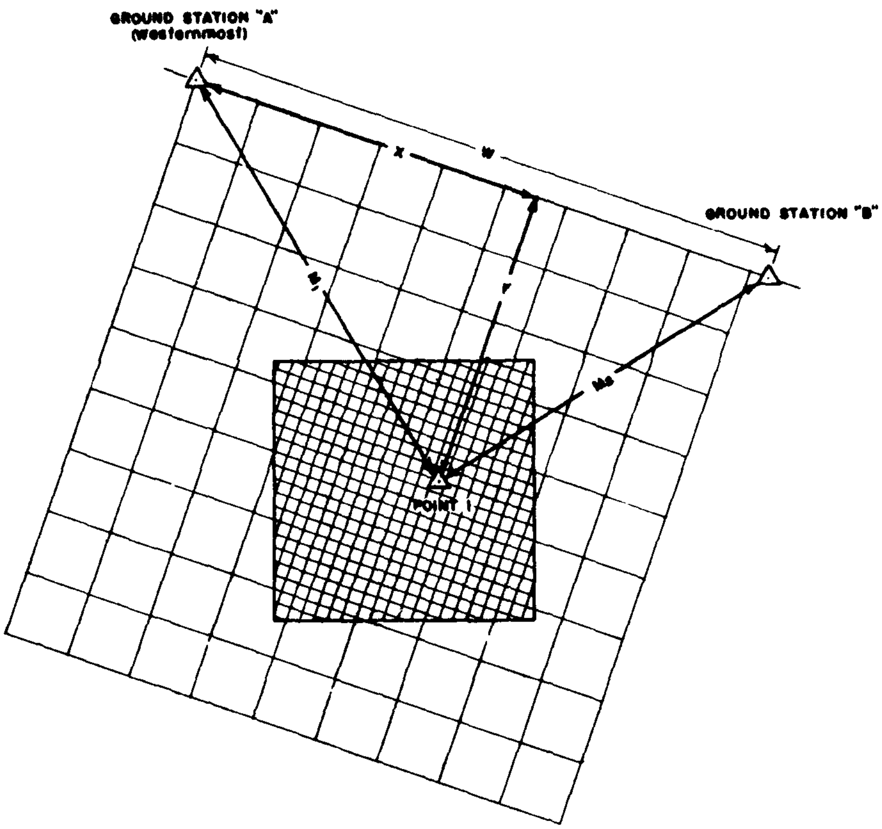
Usually, the compass heading of the aircraft remains constant, within the limits of a few degrees, for each photographic flight, and consequently, a mean heading can be used to determine constant corrections for coordinates of each photograph in that strip. If individual headings vary from this mean by more than about 5°, however, separate corrections must be computed for the coordinates of the corresponding photographs. The refinement of the correction is dependent upon the magnitude of the camera displacements; that is, the smaller the displacement, the less is the precision with which aircraft heading must be established.

	Distance from Central Meridian		
ϕ_m	1°	2°	3°
10°			1°
20°		1°	1°
30°	1°	1°	2°
40°	1°	1°	2°
50°	1°	2°	2°
60°	1°	2°	3°
70°	1°	2°	3°
80°	1°	2°	3°

FIG. 5-11. CONVERGENCE CORRECTION, UTM GRID.

Since these corrections seldom will be needed and since just one computation per flight will often be sufficient, no form is provided for the solution of ΔN and ΔE. When required, the work should be performed on a separate sheet of paper and the results entered in lines (19) and (20) of Shoran Form 5. The corrections then are added to lines (17) and (18) to obtain the final point coordinates.

10. <u>The Shoran Grid</u>. In areas where geodetic positions of the ground stations are unknown, the resulting maps will provide relative position only, and must be published without positive indication of latitude, longitude, or direction. The base line length is determined by the Shoran line-crossing method (Chapter II, par. 10) and plotting is done on a special "Shoran Grid." This grid is based on a so-called doubly equidistant projection and has



$$X = \frac{M_1^2 - M_2^2 + W^2}{2W}$$

$$Y = \sqrt{M_1^2 - X^2}$$

FIG. 5-12. THE SHORAN GRID.

the property that distance from any point on the map to either of the ground stations can be obtained as though on a plane. Distances between other points will not be absolutely true but over the comparatively small area of a normal map sheet, such errors will be negligible. Fig. 5-12 illustrates the Shoran grid. The origin of coordinates (X = 0; Y = 0) is at the westernmost ground station and the X-axis is the line passing through both ground stations. This permits plotting sheets to be laid out by constructing a simple rectangular grid in metric units to the desired working scale. Shoran control can then be plotted on sheets that have been numbered to correspond to the area in which work is to be accomplished.

Grid positions of the exposure stations are determined with the aid of Shoran Form 6 (Fig. 5-13). Space is provided at

SHORAN FORM NO. 6

SHORAN GRID COORDINATES

MISSION *Rocky Mts., Colo.*

DATE *16 April 1949* SHEET *1* OF *1*

GROUND STATION A (Westernmost) *Cheyenne, Wyo.*
GROUND STATION B (Easternmost) *Imperial, Neb.*

M_1 = DISTANCE FROM GROUND STATION A
M_2 = DISTANCE FROM GROUND STATION B
} FROM SHORAN FORM 3

$$X' = \frac{M_1^2 - M_2^2 + W^2}{2W} \qquad X = X' + \Delta X$$

$$Y' = \sqrt{(M_1)^2 - (X')^2} \qquad Y = Y' + \Delta Y$$

DISTANCE STATION A TO STATION B = W = *279,619.3* METERS

2W = *559,238.6* W^2 = *78,186,953,000*

ΔX AND ΔY = CORRECTION FOR DISPLACEMENT OF AERIAL CAMERA FROM POINT MIDWAY BETWEEN AIRBORNE ANTENNAE (ZERO FOR MOST AIRCRAFT INSTALLATIONS)

EXP. NO.	GROUND DISTANCE IN METERS		X'	Y'	ΔX	ΔY	X	Y
	M_1	M_2						
30	160,717.1	270,207.4	55,441.3	150,851.7				
31	164,072.0	271,639.1	56,002.5	154,218.5				
32	167,424.6	273,199.2	56,469.9	157,613.9				

COMPUTED BY *A.H.F.* DATE *3 Mar. 1950* CHECKED BY *C.C.L.* DATE *3 Mar. 1950*

FIG. 5-13. SHORAN GRID COORDINATES.

the top of the form for entering the names of the ground stations and the length of the base line. The reduced Shoran lengths, M_1 and M_2, are extracted from computations on Form 3 and entered opposite the appropriate exposure numbers. Since the computation of X' and Y' can be performed in the calculating machine, no space is provided for intermediate steps. Care must be taken, however, to place the decimal points correctly. The signs of the X coordinates are established in the computations. Signs of the Y coordinates are always positive and, because of the nature of the projection, numerical values increase in both directions from the base. The mapping organization always will be sufficiently well-acquainted with the area to know the relation of photography to ground stations and so no trouble should be experienced in establishing the proper direction of the Y-axis.

The X' and Y' coordinates represent the final Shoran positions except for rare missions where the aerial camera was displaced more than about 1 meter from a point midway between the airborne antennas. Displacement corrections for the Shoran grid are computed in a manner similar to that discussed in paragraph 9 for the UTM grid. In this case the formulas become:

$$X = X' + \Delta X$$

$$Y = Y' + \Delta Y$$

where X' and Y' = Shoran grid coordinates of point midway between airborne antennas

$\Delta X = D \sin Z$
$\Delta Y = D \cos Z$
D = Displacement of aerial camera from mid-point of antennas in meters
Z = Shoran grid azimuth of aircraft heading

The grid azimuth, Z, is determined from the compass heading of the aircraft as shown on the recording film, the magnetic declination, and the azimuth of the Shoran base line. Since absolute positions of the base line terminals are not known, the grid azimuth cannot be established accurately. However, its direction usually can be scaled from an existing map or otherwise estimated to the required accuracy of one or two degrees. A sketch like the one shown in Fig. 5-10 must be drawn to assure the selection of the proper signs for all variables. Corrections can then be computed and entered in the appropriate columns of Form 6.

11. Conversion from Geographic to Shoran Position. On rare occasions it may be desirable to add a geographic graticule to maps that have been compiled on the Shoran grid. This can only be done, however, after the geographic positions of the ground stations have been established. The procedure involves computing the Shoran

coordinates of even 1-, 5-, or 10-minute (depending upon map scale) intersections of latitude and longitude, plotting the positions on the Shoran grid, and then connecting the points with straight lines. The resulting graticule is a doubly equidistant projection based on the two ground stations and, within the small area covered by a normal map sheet, differs very little from more common projections. If the map is published in this form, appropriate notation should be made in the legend.

The first step of the computation requires establishing the geographic coordinates of both ground stations. This may necessitate a conversion from UTM coordinates on Army Map Service Form No. 3-141 (Fig. 5-14). A complete discussion of the method is given in AMS TM No. 19, "Universal Transverse Mercator Grid." The next step is to determine the value of six coefficients which are to be used in the actual position computation. Fig. 5-15 illustrates the required solution. Coefficients are constant for any given pair of ground stations and, consequently, must be computed just once. Coordinates of the individual points are determined by the solution shown in Fig. 5-16. Printed forms will not be needed because of the infrequency with which the method will be applied. No difficulty should be encountered in the solution if Figs. 5-15 and 5-16 are followed carefully and if the following points are noted:

GEOGRAPHIC COORDINATES FROM UNIVERSAL TRANSVERSE MERCATOR GRID COORDINATES

Station *Ground Station A* Location *Cheyenne, Wyo.*
Zone *13* Spheroid *Clarke 1866* Unit *Shoran Section*

E	*514 712 24*	q always positive (+)	
FE	−500 000 00	q	*.014 712 24*
E′	*14 712 24*	q²	*.000 216 45*
		q³	*.000 003 18*
		q⁴	*.000 000 05*

N	*4 558 667 73*
	4 558 667 73
Tabular (IX) (Even min. of φ)	*42 912 525*
Interpolation for seconds of φ′	*9 530*
Δ² (IX) from graph	*–*
(IX)	*42 922 055*

Interpolating N in (I). φ′	*41° 10′ 52.568″*
Tabular (VII) (Even min. of φ′)	*2 220 534*
Interpolation for seconds of φ′	*1 135*
(VII)	*2 221 669*
(VII) q² (seconds)	*481″*
(VII)q²	*00′ 00.481″*
(VIII)	*33.03*
(VIII)q⁴ +	*00′ 00.00″*
D6 from graph	*00.00″*
LATITUDE, Φ	*41° 10′ 52.087″*

Tabular (X) (Even min. of φ′)	*444 374*	(IX)q +	*631 480″*
Interpolation for seconds of φ′	*374*	(X)q³ −	*001″*
(X)	*444 748*	E5 +	*000″*
		Δλ (seconds)	*631 479″*
East when E′ is (+) West when E′ is (−) Δλ	*0° 10′ 31.479″*		
Central Meridian, λ₀	*105° 00′ 00.000″*		
LONGITUDE, λ	*104° 49′ 28.521″*		

Date Computed *28 Mar. 1950* By *A.H.F.* Checked by *C.C.L.*

ARMY MAP SERVICE
CORPS OF ENGINEERS U. S. ARMY 204475 FORM NO. 3-141

FIG. 5-14. GEOGRAPHIC COORDINATES FROM UTM POSITION.

COMPUTATION OF COEFFICIENTS (K'S)
FOR USE WITH
POSITION COMPUTATION, GEOGRAPHIC TO SHORAN

STATION A	SPHEROID *Clarke 1866*	STATION B
Cheyenne, Wyoming	NAME	*Imperial, Nebraska*
41° 10' 52."087	LATITUDE (ϕ)	40° 30' 45."654
104° 49' 28."521	LONGITUDE (λ)	101° 37' 39."439
.032 291 51	A' *	.032 292 78
.752 631 7	Cos ϕ	.760 262 2
233 .074 246	$\frac{10 \text{ Cos } \phi}{A'}$	235.427 919
54,323 .570	$K_1 = \left(\frac{10 \text{ Cos } \phi}{A'}\right)^2$	55,426.305
.032 416 17	B *	.032 419 98
308 .488 016	$\frac{10}{B}$	308.451 763
95,164 .856	$K_2 = \left(\frac{10}{B}\right)^2$	95,142.490
.221 39 x 10^{-6}	C x 10^2 *	.216 85 x 10^{-6}
2,295.241	$K_3 = 2 K_1 K_2 (C \times 10^2)$	2,287.072
.020 306 0	$3e^2$ **	.020 306 0
46.428	$K_4 = \frac{K_3 A}{B} \cdot (3e^2)$	46.259
.007 30	F x 10^{10} *	.007 35
.001 042 742	A'^2	.001 042 824
.658 441 7	Sin ϕ	.649 616 3
4.610	$K_5 = \frac{\text{Sin } \phi \, (F \times 10^{10})}{A'^2}$	4.579
.874 852 4	Tan ϕ	.854 463 6
42.397	$K_6 = \frac{.01616 K_3}{\text{Tan } \phi}$	43.254

NOTE:

* Factors A', B, C, and F are obtained from tables using the latitude (ϕ) of the station as the argument.

** Eccentricity of the reference spheroid.
For the Clarke Spheroid of 1866; $3e^2 = .0203060$

FIG. 5-15. COMPUTATION OF COEFFICIENTS - GEOGRAPHIC TO SHORAN.

POSITION COMPUTATION GEOGRAPHIC TO SHORAN

(Coefficients (K's) obtained from separate computation)

POINTS LOCATED

P_1 Sheet Corner 1

P_2 " " 2

P_3 " " 3

P_4 " " 4

STATION A Cheyenne, Wyo.		STATION B Imperial, Neb.	
ϕ_A 41° 10' 52".087	λ_A 104° 49' 28".521	ϕ_B 40° 30' 45".654	λ_B 101° 37' 28".439
K_1 64,322.570	K_4 46.428	K_1 55,426.806	K_4 46.862
K_2 96,164.856	K_5 4.610	K_2 95,142.430	K_5 4.672
K_3 2,895.241	K_6 42.397	K_3 2,297.072	K_6 43.264

$$M^2 = K_1p^2 + K_2q^2 - K_3p^2q + K_4q^3 - K_5p^4 - K_6p^2q^2$$

(M IN KILOMETERS)

$$X = \frac{M_1^2 - M_2^2 + W^2}{2W}$$

$$Y = \sqrt{M_1^2 - X^2}$$

DISTANCE A TO B = W = 279.6193 KM.

W^2 = 78,186.95

2W = 559.2386

	P_1		P_2		P_3		P_4	
	λ_P 104° 45'		λ_P 104° 30'		λ_P 104° 30'		λ_P 104° 45'	
	ϕ_P 39° 45'		ϕ_P 39° 45'		ϕ_P 39° 30'		ϕ_P 39° 30'	
	STATION A	STATION B	STATION A	STATION B	STATION A	STATION B	STATION A	STATION B
$\Delta\lambda = \lambda_P - \lambda$	-4'28".521	+3°07'28".561	-19'28".521	+2°52'28".651	-19'28".521	+2°52'28".561	-4'28".521	+3°07'28".561
$\Delta\phi = \phi_P - \phi$	-1°25'52".087	-45'45".654	-1°25'52".087	-45'45".654	-1°40'52".087	-1°00'45".654	-1°40'52".087	-1°00'45".654
$p = \Delta\lambda'' \times 10^{-4}$	-.0268521	+1.1240561	-.1168521	+1.0340561	-.1168521	+1.0340561	-.0268521	+1.1240561
$q = \Delta\phi'' \times 10^{-4}$	-.5162087	-.2745654	-.5162087	-.2745654	-.6052087	-.3645654	-.6052087	-.3645654
p^2	.0007210	1.2635021	.0136544	1.0692720	.0136544	1.0692720	.0007210	1.2635021
q^2	.2664660	.0753862	.2664660	.0753862	.3662776	.1329079	.3662776	.1329079
p^2q	-.0003715	-.3469140	-.0070349	-.2935851	-.0082638	-.3898136	-.0004364	-.4606291
q^3	-.1367570	-.0206984	-.1367570	-.0206984	-.2216744	-.0484536	-.2216744	-.0484536
p^4	.0000005	1.5964376	.0001864	1.1433426	.0001864	1.1433426	.0000005	1.5964376
p^2q^2	.0001914	.0952506	.0036244	.0806084	.0050013	.1421147	.0002641	.1679234
$+K_1p^2$	+ 39.17	+ 70031.25	+ 741.76	+ 59265.80	+ 741.76	+ 59265.80	+ 39.17	+ 70031.25
$+K_2q^2$	+ 25260.56	+ 7172.43	+ 25260.56	+ 7172.43	+ 34856.76	+ 12645.19	+ 34856.76	+ 12645.19
$-K_3p^2q$	+ .85	+ 793.42	+ 16.15	+ 671.46	+ 18.97	+ 891.55	+ 1.00	+ 1053.49
$+K_4q^3$	- 6.35	- .96	- 6.35	- .96	- 10.29	- 2.24	- 10.29	- 2.24
$-K_5p^4$	- 0	- 7.31	- 0	- 5.24	- 0	- 5.24	- 0	- 7.31
$-K_6p^2q^2$	- .01	- 4.12	- .15	- 3.49	- .21	- 6.15	- .01	- 7.26
	M_1^2 = 25294.22	M_2^2 = 77984.71	M_1^2 = 26011.97	M_2^2 = 67099.99	M_1^2 = 35606.99	M_2^2 = 72700.91	M_1^2 = 34886.62	M_2^2 = 83712.12
X	45.591		66.338		73.323		52.501	
Y	152.367		147.008		173.870		179.249	

FIG. 5-16. POSITION COMPUTATION - GEOGRAPHIC TO SHORAN.

a. Factors A', B, C, and F are dependent upon the reference spheroid and are obtained from tables using the latitude as an argument. For the Clarke spheroid of 1866, logarithms of the values are obtained from U. S. Coast and Geodetic Spec. Publ. No. 8, "Formulas and Tables for the Computation of Geodetic Positions." Terms must be converted to their natural form for use in the machine computation.

b. The numerical values of terms $+K_1p^2$ and $+K_2q^2$ will always be plus (+) and those of terms $-K_5p^4$ and $-K_6p^2q^2$ will always be minus (-). The values of terms $-K_3p^2q$ and $+K_4q^3$ may be either plus or minus depending upon the sign of term q.

c. Distances are listed in kilometers rather than in meters as employed usually in other Shoran computations.

CHAPTER VI

FLYING HEIGHT DETERMINATION

CHAPTER VI

FLYING HEIGHT DETERMINATION

1. General. The geometry of the formula for reducing Shoran measurements to geodetic distances calls for the true flying height of the aircraft at the instant of each exposure. In the mapping application, however, where the Shoran position of several photographs must be computed, the solution is greatly simplified if a constant equal to the mean flying height is used in the computation of all exposures. This simplification produces no significant errors in the final results except in those few instances where individual exposures deviate from the mean by more than about 100 feet. In these, small corrections must be applied to the corresponding distances.

The face of a barometric altimeter with pointers reading to the nearest 20 feet appears in each altimeter recorder exposure. A second, though less accurate, barometric altimeter appears on the Shoran recorder film and can be used where altimeter recorder values are unavailable. Altimeters of this type, however, are simple aneroid barometers calibrated to read correct altitude above sea-level only under an assumed standard atmospheric condition and, for this reason, the indicated reading can be in error by as much as 1,000 to 2,000 feet, or more. The instrument does, however, give fairly reliable readings for flying height differences; consequently, true mean flying height is determined by other methods, and the difference between the true height and that indicated is applied as a correction to any individual exposure recording for which the true height is needed. The following methods are available for establishing true flying height:

a. Meteorological observations.

b. Radio altimeter carry.

c. Photogrammetric.

2. Meteorological Observations. One method of establishing the necessary flying height is through computations based on meteorological observations made at the time the photography is flown. Briefly, the method consists of computing the thickness of air layers between successive pressure levels as indicated by readings of temperature, pressure, and humidity. By adding these thicknesses together, the altitude corresponding to any pressure can be determined. The mean altimeter reading is then converted to its basic pressure level value, and the corresponding altitude is taken from the meteorological computations. In some cases, the upper air data gathered regularly at Air Weather Service or other governmental

weather stations will be suitable. At other times the use of a special weather observing airplane will be required. The proper method of gathering the necessary data will be determined by the Air Force unit, and the necessary corrections will be supplied with the aerial photography, if called for in the specifications.

3. Radio Altimeter Carry. In some special cases the "radio altimeter carry" method may be used to determine true flying height. This method requires the simultaneous recording of readings from both the barometric and radio altimeters as the mapping aircraft flies over an area of known elevation. The radio altimeter reading plus the elevation of the datum area gives the true flying height above sea level. Thereafter, the barometric altimeter provides information concerning flying height differences. Upon completion of the mission, the plane again flies over the datum area to take readings of both instruments, thereby furnishing a means of adjusting the barometric values for temporal variation in height of the pressure level. Any needed correction for pressure level gradient between the reference area and the photographed area is obtained from standard level charts published by the Weather Bureau or the Air Weather Service. The radio altimeter carry method, then, provides a way of calibrating the barometric altimeter so as to eliminate the need for meteorological observations at the time and place of photography. It also permits "carrying" these elevations for quite some distance from a datum area to the area to be photographed.

A limitation of this method is the fact that a rather large flat area must be used for reference, since the altimeter beam covers a cone of several degrees and, in rough terrain, it is likely to indicate distance to some high peak instead of height above the point directly beneath the aircraft. Large lakes of known elevation or sea water make ideal reference areas and, if available, should produce reliable results. Although no past tests have permitted an evaluation of its accuracy, it is possible that this application may prove useful in specific cases.

4. Photogrammetric Methods. Photogrammetric procedures offer a third method of establishing true flying height, provided one or two identifiable points of known elevation appear somewhere in the mapping photography. The method is somewhat similar to the radio altimeter carry method, in that flying height above the datum is first determined and then added to the datum elevation in order to establish exposure height. As before, flying height differences are taken from the recordings of the barometric altimeter. Any photogrammetric determination of height above datum requires the availability of sufficient ground control to permit a graphical or analytical resection of the exposure station. Where several control points appear in one aerial photograph, flying height may be established by any one of the several existing methods. Multiplex

methods, however, offer the simplest and most direct solution and, in the Shoran application, require the availability of only a single datum elevation point. Shoran positions computed with the best available estimate of flying height give an approximate scale, following which, a special "BZ" curve method can be used to level the models without recourse to ground points. With absolute orientation established in this manner, exposure height can be determined from the camera frame size and focal length, and the elevation of one datum point in the model. However, to be of value, the camera constants must have been measured with high precision and, for this reason, the use of an accurate, well-calibrated mapping camera is mandatory in areas where photogrammetric methods are to be used.

5. Flying Height Determination by Multiplex Methods. Correctly oriented multiplex models represent an accurate, true-to-scale miniature of conditions at the instant of the aerial exposures. If diapositives could be made from aerial negatives unaffected by film shrinkage and used in projectors having a principal distance of exactly 28.182 mm (specifications permit a tolerance of $\pm.015$ mm in this setting) then the height of the emergent node of the projector lens above any point within the model would represent the exact scale height of the photographic airplane above the corresponding point on the ground. Under these conditions, flying height could be established by measuring the vertical distance of the node above a point of known elevation, dividing by the model scale, and adding in the height of the datum point. The small errors of film shrinkage and projector principal distance will normally introduce no significant error in maps compiled from the models, but they may cause sufficient error in flying height determination to affect adversely the computed Shoran positions. To circumvent this possibility, flying heights are determined through a comparison of accurately determined camera constants with the size of the projected diapositive after absolute orientation has been accomplished.

a. Fig. 6-1, which illustrates the theory of flying height determination by this method, represents one projector of a correctly oriented multiplex model, and shows a tilted axis corresponding to the tilt assumed to have been present when the original exposure was made. The line AE represents a horizontal plane through A, the datum point of known elevation. The vertical distance OB (= P) is the height of the projector node above the datum plane and is the true scale flying height above datum under the assumed conditions of exact principal distance and no film shrinkage. OC is the principal axis of the projector and GJ is an imaginary plane at right angles to OC and positioned so that OC = OB = P. The distance, d, across the diapositive between opposite fiducial marks corresponds to the distance D in the imaginary plane GJ. From the geometry of the figure it can be seen that:

$$\frac{f}{P} = \frac{d}{D}$$

or

$$P = \frac{fD}{d}$$

The distance D can be measured by first reading the elevation of point A, then leveling the projector with the tip and tilt screws, and finally measuring the distance between opposite fiducial marks in the plane of the initial reading of the datum elevation.

The multiplex reduction printer is designed to give a reduction of the multiplex diapositive from the aerial negative in the same ratio as principal distance of the projector is to calibrated focal length of the aerial camera (TM 5-244). This means, then, that the following ratio is obtained:

$$\frac{M}{d} = \frac{F}{f}$$

where M = Camera frame size between opposite fiducial marks
d = Diapositive image size between opposite fiducial marks
F = Calibrated focal length of aerial camera
f = Nominal principal distance of multiplex projectors

If this formula is combined with the one previously developed, the following formula for projection distance is obtained:

$$P = \frac{D}{M} \cdot F$$

This formula gives the actual scale flying height and is independent of errors caused by film shrinkage. True exposure height is determined by dividing the quantity, P, by the model scale and adding the elevation of the datum point. The true focal length, F, and camera size, M, will be known, since they are called for in the specifications for photography.

b. The first step in multiplex flying height determination will be to select a strip of five or six models within which one or more identifiable points of known elevation appear. A datum point near the principal point of one of the photographs is desirable in order to minimize any possible errors resulting from an inability

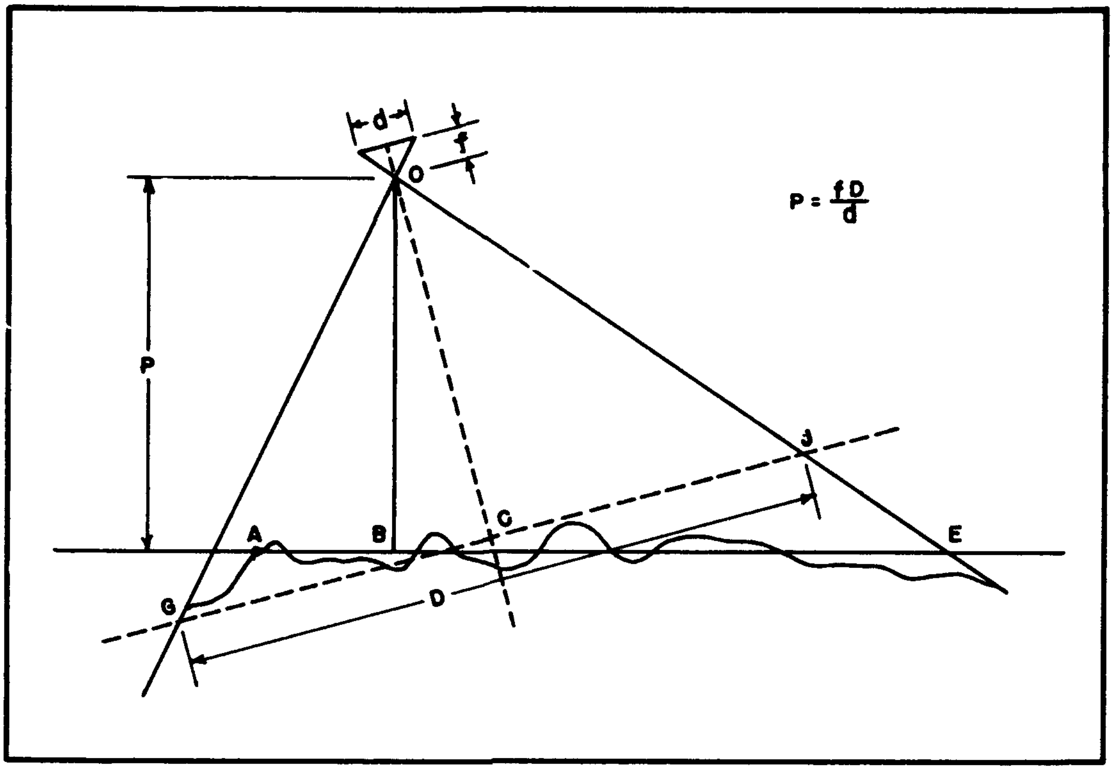


FIG. 6-1. THEORY OF MULTIPLEX FLYING HEIGHT DETERMINATION.

to level the model perfectly. The entire strip is then placed in the multiplex and leveled as a unit. Cross flight photography and the special BZ curve method are used where insufficient control is available to "strip level" in the conventional manner. The strip is then carefully scaled to the Shoran positions corresponding to the two end photographs. In this scaling operation, the displacements of the true from the indicated photo plumb points are taken into account by the methods outlined in Chapter VII. Shoran positions are then computed, using the flying height value read from the recorded altimeter plus any correction it may be possible to estimate. The work sheet plotting scale is selected so as to produce a projection distance as close as possible to 360 mm (TM 5-244).

Next, the model containing the datum point is individually leveled to existing vertical control, if available, or if not, by tipping the multiplex bar so as to level the portion of the BZ curve through the model in question (Chapter VII). With absolute model orientation thus established, the tracing table reading of the datum elevation point is noted and recorded. The projector having its principal point nearest the datum point, is then leveled with the tip and tilt screws, using the multiplex nadirscope (Fig. 7-4) for reference. The projected diapositive size can now be measured in the plane of the datum elevation.

Measurement of the projected frame dimension is made by resetting and locking the platen at the previous tracing table reading of the datum point. The dot of light is placed first at one and then at the opposite image edge near the fiducial marks and the points are projected to the work sheet by dropping the pencil point. Frame dimensions in either direction may be used, but the length in line of flight can usually be measured with greatest accuracy. This operation is very exacting, and must be performed with the utmost care. It may even be desirable to replace the pencil with an accurately centered metal point during this step. Measurement of the distance between the plotted points is accomplished with a beam compass and meter bar. Readings are recorded to the nearest .02 mm. Exposure height is then determined by substitution in the following formula:

$$H = \frac{.00328D}{MS} \cdot F + A$$

where

H = Exposure height above sea level, in feet

D = Projected diapositive size (in millimeters) in the plane of datum elevation

M = Camera frame size (in millimeters) between opposite fiducial marks and corresponding to measurement of projected diapositive

S = Horizontal model scale, expressed as a representative fraction

F = Calibrated focal length of aerial camera, in millimeters

A = Elevation of datum point above sea level, in feet

Of course, if the altimeter readings show a deviation from the mean for the particular exposure used in this determination, a corresponding correction must be added in order to establish the true mean flying height of the entire mission.

CHAPTER VII

MULTIPLEX BZ CURVE ORIENTATION METHODS AND RELATED AUXILIARY EQUIPMENT

CHAPTER VII

MULTIPLEX BZ CURVE ORIENTATION METHODS AND RELATED AUXILIARY EQUIPMENT

1. The BZ Curve Method. Multiplex operations involving either flying height determination or, later, map compilation require absolute orientation of the models in units of about seven projectors each. Since Shoran control is effective at the photo plumb points, it is necessary that orientation be sufficiently accurate to insure proper recovery of these plumb points. Multiplex equipment furnishes reliable horizontal accuracy throughout an extension of seven exposures, but the accrued error in projection tilt will usually become too great to permit the use of the indicated projector plumb points in scaling to the Shoran positions. The BZ curve provides a means of overcoming this difficulty. In areas where identifiable vertical control is available at each end of the strips, leveling can be accomplished by adjusting the handwheels and foot screws of the multiplex frame until the best average fit to the points is obtained. The BZ curve method is then needed only to find the displacement of the true photo plumb points from the projector plumb points. Frequently, however, Shoran mapping operations must be conducted over areas where very little control, either vertical or horizontal, exists; hence, the problem of establishing proper horizontalization becomes important. Under these conditions the BZ curve method also provides a means of strip leveling in which only the differences in exposure heights, as indicated by the barometric altimeter, are used.

In the extension of multiplex models from a correctly oriented starting model, it is usually found that the height of adjacent projectors gradually decreases, even though the aircraft flying height remained constant throughout the entire strip. This phenomenon, at least in part, results from the distortion introduced by the particular aerial-camera--reduction-printer combination used in making the diapositives, and from the position on either side of the flight line at which parallax was removed from the models. If projector height is plotted against distance along the flight line, and a smooth line drawn approximately through the points, a BZ curve of the type shown in Fig. 7-1 will result. An exaggerated vertical scale is used to emphasize the curvature. Any slight deviation of the plotted heights from a smooth curve is probably a result of small variations in projector principal distances, or of differences in the way parallax was removed in the different models.

a. The actual preparation of a BZ curve requires the measurement of the height differences, and of the horizontal spacing of a group of projectors that have been brought into correct relative orientation. (The latter is done by the removal of parallax and tieing together the models by bringing common pass points along the flight line to the same elevation.) Extreme care must be taken at all stages in the operation, and it is especially important that parallax be removed at the same distance above and below the flight line in all models. In places where no vertical control is available, the first model is leveled as nearly as possible, using estimates of the height of terrain features. The remaining five or six models are then "tied in" and the strip is adjusted to an approximate working scale by fitting the principal points of the end projectors to their corresponding Shoran positions. If true flying height has not been established at this point, Shoran positions are computed from the best available estimate, usually based on readings of the recorded altimeter.

The BZ curve for this orientation can now be prepared. Either of the end projectors is selected as the starting point and its position is taken as the origin of coordinates of the graph. Plotting is best done on graph paper having 10 by 10 squares to the inch, using a horizontal scale of 1 inch on the graph equal to 200 mm on the work sheet, and a vertical scale of 1 inch on the graph equal to 2 mm in projector height. The abscissas are determined by spotting the projector plumb points with the multiplex nadirscope and scaling distances along the flight line from the first projector with an ordinary millimeter rule. Ordinates are established by taking multiplex height gage readings to the top of the boss of each projector, and then subtracting the reading of the starting projector from that of the others. It is also necessary that a correction be applied to the height of any exposure for which the recorded altimeter shows a deviation in flying height from that of the starting projector. The amount of the correction is equal to the elevation difference converted to millimeters at the model scale and, as a result, the plotted position must be moved up in cases where the exposure height is lower than that of the first projector. A smooth curve, that passes as nearly as possible through all the plotted points, is drawn. Slight deviations of the points from the curve are permissible if exact coincidence would tend to introduce unevenness.

b. This initial curve shows the approximate strip orientation (in line of flight) as based on the estimated horizontalization of the starting model. The entire strip can now be leveled in the X, or "tip," direction by adjusting the handwheels at each end of the frame so that the ordinates of the BZ curve are the same at the two points representing the end projectors. This means that the end projectors will be brought to the same height above the table, after consideration is given to the correction for flying height differences and to any small correction resulting from the failure of the curve to pass exactly through the plotted positions.

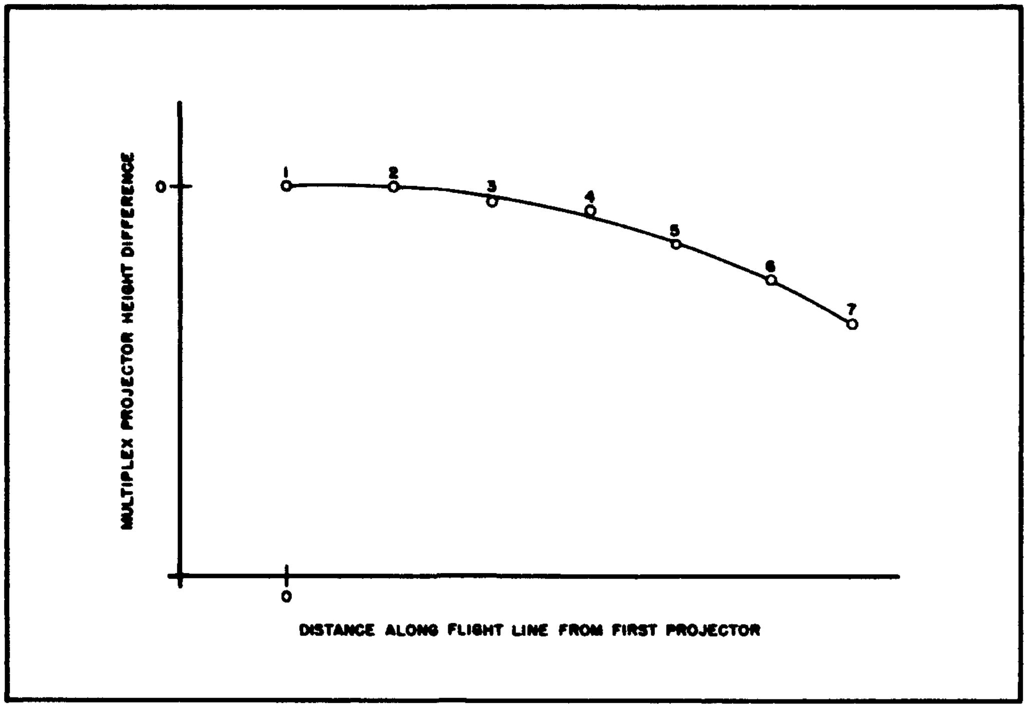


FIG. 7-1. TYPICAL MULTIPLEX BZ CURVE WITH CORRECTLY ORIENTED STARTING MODEL.

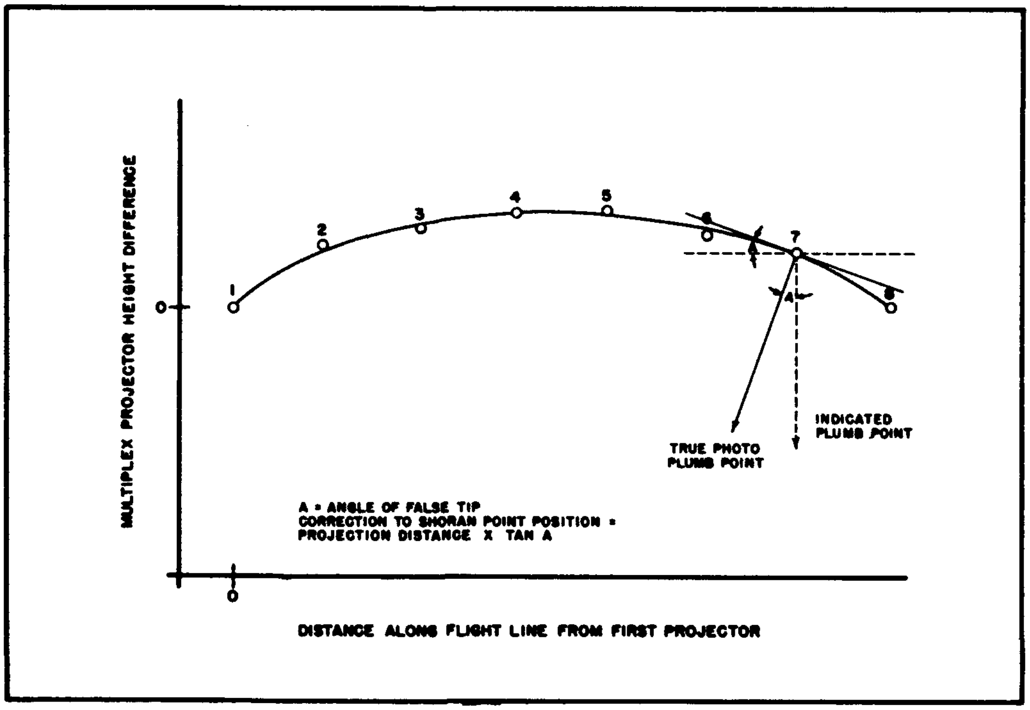


FIG. 7-2. TYPICAL "LEVEL" BZ CURVE SHOWING METHOD OF CORRECTING FOR FALSE TIP.

The final BZ curve can now be prepared in exactly the same manner as the first. Fig. 7-2 illustrates a "level" BZ curve of this type. In actual operations the end projectors are adjusted to the same elevation, plus any correction for flying height difference, immediately after bringing the strip to approximate scale. In most instances, this produces a level curve at the first attempt, since only rarely will a smooth curve fail to pass through the end points.

The level BZ curve is assumed to represent the profile of a horizontal ground line through the multiplex models. Elevations directly beneath the end projectors are taken as being true, and elevations at other points along the flight line are corrected by subtracting an amount equal to the ordinate of the curve at that point. In this manner, a line of correct relative elevations can be established along the flight line of any strip. Points on either side of the center are likely to contain rather large errors, however, unless the model level in the tilt (Y) direction can be established through reference to wide flat rivers, large bodies of water, or other reliable elevation features. To overcome this limitation, the flight plan illustrated in Fig. 4-1 is usually used in areas with little or no vertical control. This arrangement of flight strips permits the establishment of lines of correct relative elevation at right angles to the normal mapping photography and at intervals of about every five or six models. The regular parallel flight strips can then be leveled in the tip direction by the BZ curve method and in the tilt direction through reference to the elevation differences established along the center lines of the cross flights.

c. Another application of the BZ curve is its use in finding the displacement between the true photo plumb point and the point directly beneath the projector lens as indicated by the multiplex nadirscope. Where the models can be individually oriented, these two points are the same. In strip orientation, however, the fall-off in projector height also introduces a "false tip" which must be analyzed and corrected in the course of scaling to Shoran control (Fig. 7-2 illustrates the method used). The false tip in any projector is the angle between a horizontal line and a tangent to the curve at the point representing the projector. The displacement between the true photo plumb point and the indicated projector plumb point is equal to the projection distance times the tangent of the angle of false tip. In practice, the projection distance is found by measuring the vertical distance from the model surface at the indicated plumb point to the top of the projector boss, and then subtracting the distance from the emergent node of the lens to the top of the boss In this operation, the height of the top of the boss above the emergent node may be considered a constant of 3.89 mm for all Army projectors. The tangent of the false tip angle is merely the slope of the line tangent to the curve expressed as a ratio of ordinates to abscissas.

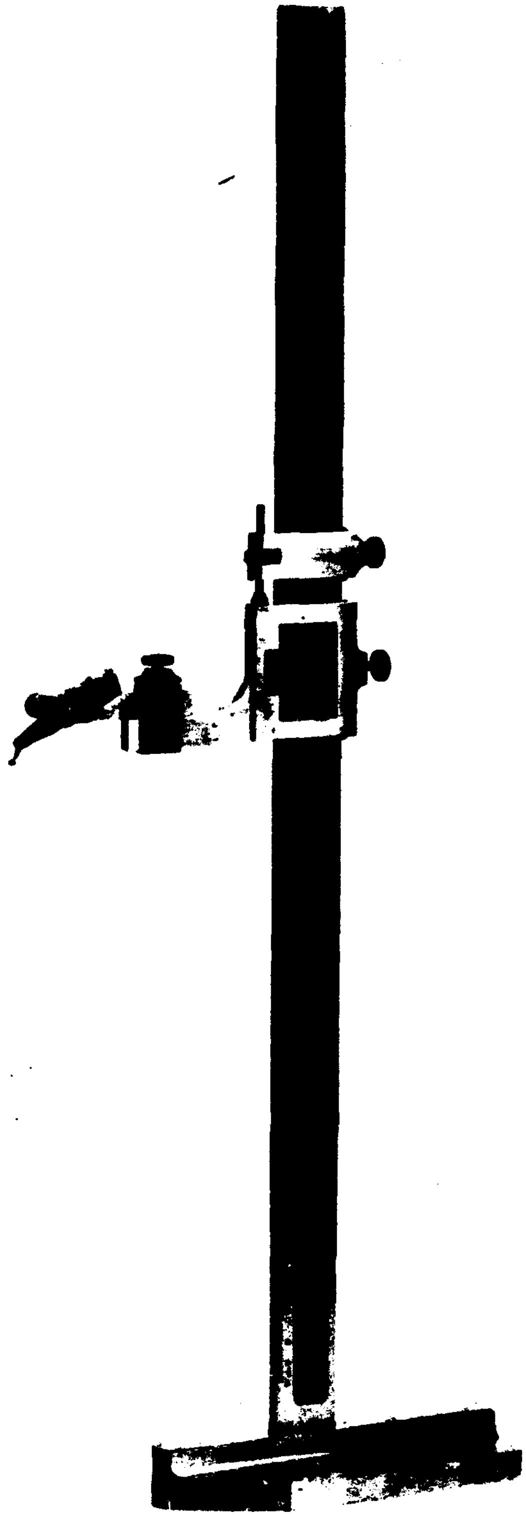


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FIG. 7-3. MULTIPLEX HEIGHT GAGE WITH ATTACHED INDICATOR DIAL.

Proper orientation of the multiplex strips requires adjustment of the scale so as to obtain the best average fit of all photo plumb points to their corresponding Shoran positions. Because of the presence of false tip a new scale point must be spotted for each plotted Shoran position so as to permit use of the indicated projector plumb points. With the normal "concave downward" BZ curve the displacement of the new scale points will be smallest at the center of the strip and will increase toward the ends. The direction of this displacement from the plotted points will be outward from the center and along a line parallel to the line of flight.

d. Occasionally, the BZ curve may take the form of a straight horizontal line and, in rare instances, may be concave upward. Under such conditions the same general principles still apply, but care must be taken to alter the sign of the elevation and displacement corrections accordingly. It should also be noted that different operators may not secure identical BZ curves from extensions of the same strip, nor will the same operator always duplicate his first curve when orienting a strip for the second time. In either case, however, the final net results should be about the same. It is, therefore, necessary to redraw the BZ curve and compute a new set of corrections at any time a strip must be oriented for a second time.

2. Multiplex Height Gage. Vertical distances needed in multiplex operations are made with the height gage and indicator (feeler gage) shown in Fig. 7-3. The instrument is calibrated to read in millimeters on one side of the rule and in inches on the other. A vernier permits direct readings of .02 mm or .001 inch, though only the millimeter readings will normally be used in multiplex work. The primary functions of the height gage are the measurement of height differences to the tops of the projector bosses and the establishment of vertical distance from the tracing table platen to the top of a projector boss. Since the rule is calibrated from an arbitrary datum, only height differences and not heights above the surface on which the base is set can be obtained.

The dial indicator is attached to the horizontal stud of the height gage vernier and the switch lever is adjusted so that the pointer rotates as pressure is applied to the under side of the ball feeler point. This feeler point can be adjusted to almost any convenient angle but the setting must remain constant throughout any series of measurements. Readings to the top of any surface are then made by adjusting the vernier until the indicator dial reaches a pre-selected constant reading. In this manner, a constant pressure is applied in the measurement to all surfaces and a true height difference is assured. In order to read to the top of a rounded surface such as the projector boss, the entire gage is moved slightly back and forth so that movement of the indicator dial will reveal the high point on the surface.

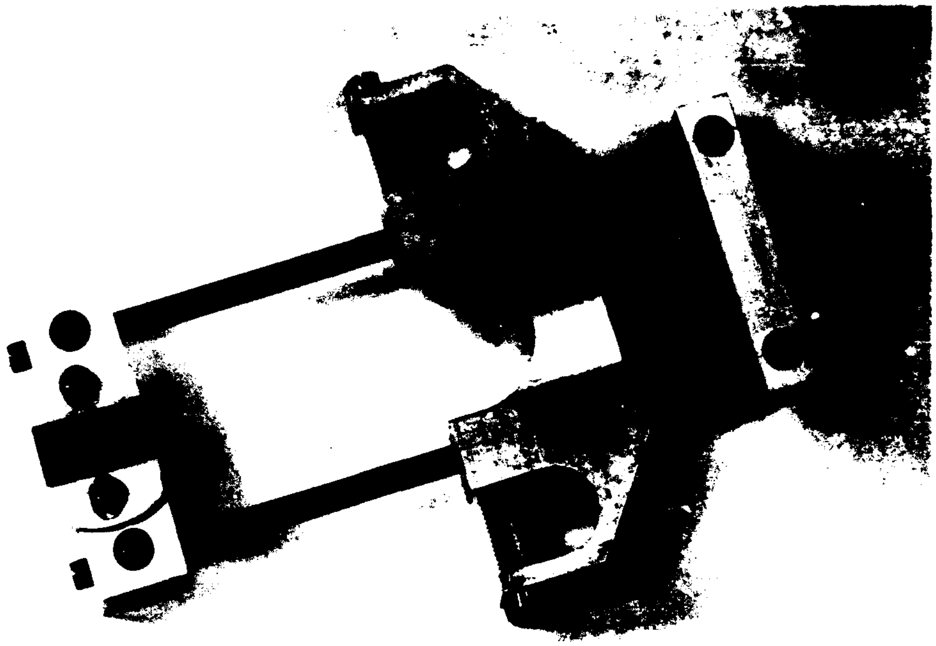

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FIG. 7-4. MULTIPLEX NADIRSCOPE.

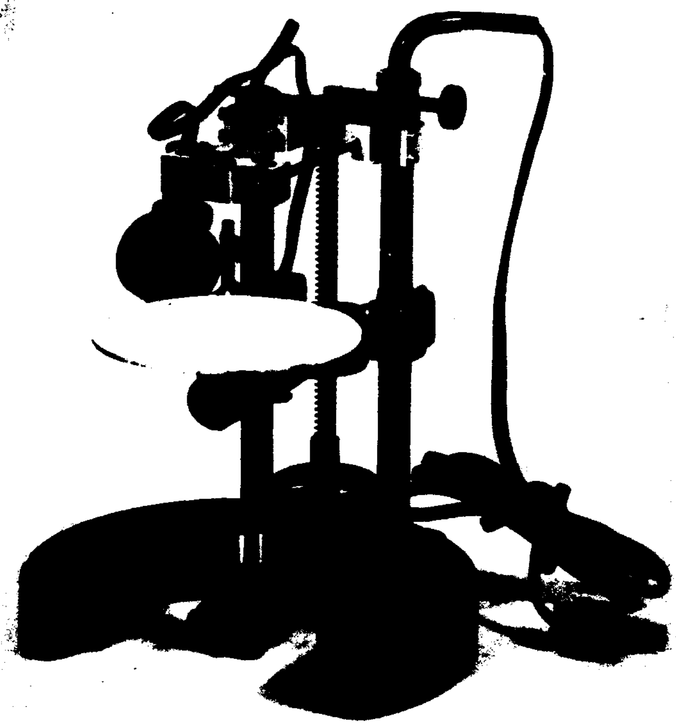

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FIG. 7-5. NADIRSCOPE ATTACHED TO MULTIPLEX TRACING TABLE.

3. Nadirscope. The nadirscope (Figs. 7-4 and 7-5) is used to find the point vertically below a multiplex projector lens. Standard Corps of Engineers nomenclature is "Nadirscope, Photogrammetric, for Multiplex Tracing Table." It consists of a finely etched cross suspended directly over the dot of light in the tracing table platen. Moving the table around until the dot of light is centered in the shadow of the cross brings the table directly under the projector lens and permits the plumb point to be marked by dropping the pencil point. The instrument may also be used in leveling a projector since the principal point and nadir point are coincident when the projector is truly level. In this operation the tracing table is first set at the projector plumb point and the tip and tilt screws adjusted until the principal point is centered over the dot of light.

In attaching the nadirscope to the tracing table a binding of the sliding parts may sometimes be encountered as a result of variation in the spacing of the vertical columns. The use of thin shims will ordinarily relieve this situation. Once in position, it can be left in place since the cross hairs slide out of the way when not needed. When the nadirscope is in use, the frame is locked into position with the knurled screw and the tracing table platen lowered so as to give the greatest possible distance between cross hairs and shadow. It is also necessary that the centering be checked from time to time to insure that verticality of pencil, point of light, and cross hairs remains true. Any necessary adjustment is started by making sure that the pencil is exactly centered under the dot of light with the platen at its lowest position. Next, the plumb point of a projector is plotted. The entire tracing table is then rotated through 180° and the plumb point is again plotted. Any displacement between the two plotted points represents twice the centering error and must be removed by means of the adjusting screws of the nadirscope. Exact centering is achieved by repeating the procedure until coincidence is obtained. As a final check, the cross hairs should be moved out of position and then back and the test re-run to be sure that the frame always returns to the same position.

CHAPTER VIII

MULTIPLEX MAPPING

WITH AREA COVERAGE PHOTOGRAPHY

CHAPTER VIII

MULTIPLEX MAPPING

WITH AREA COVERAGE PHOTOGRAPHY

1. General. The nature of Shoran control is such that multiplex scaling cannot be accomplished in the normal manner. Various random errors inherent in present equipment preclude absolute reliance on any one point, even when sufficient vertical control is available to permit positive recovery of the photo plumb points. Maximum accuracy is obtained by scaling the nadir points of all photographs in the area to the best average fit of the corresponding Shoran positions. In this way, part of the random error is averaged out so as to produce a map with greater internal accuracy than could otherwise be expected. The desired results are obtained by first orienting the photography in strips of five to seven models each and scaling to the best mean fit of the Shoran positions. Pass points common to adjacent strip units are then spotted along the edges of the plotting sheets. Finally, the several sheets comprising one work area are matched along the grid lines and common detail points are examined for coincidence. Pass points can then be graphically adjusted to remove any evidenced internal position or scale disagreement. Once these corrections have been made, compilation of map detail is accomplished in the conventional manner.

2. Preparation of Plotting Sheets. Shoran points are normally plotted on the UTM grid though occasionally the Shoran grid will be employed. In either case, the general procedure will be the same because both are rectangular grids. Spacing of the grid lines will depend largely upon the scale to be used in the multiplex operations, though a distance of from four to six inches on the plotting sheet is usually desirable. For example, an interval of 2,000 meters will be found satisfactory for plotting scales of approximately 1:17,000.

To facilitate the planning of sheet layout, the UTM grid should be constructed on one copy of the photo index. This can be done with sufficient accuracy by noting the coordinates of the centers (plumb points) of corner photographs, interpolating for the intermediate even grid values, and connecting appropriate points with straight lines. The line interval should correspond to that used on the plotting sheets and the grid drawn in light colored ink so as to provide good contrast with the dark index. A geographic grid representing borders of the published map sheets can be added by computing the UTM coordinates of the necessary intersections and then connecting the plotted positions.

The control extension sheets should be of some stable, transparent medium such as acetate. Standard nomenclature for this material is "celulose acetate, translucent Eastman Safety topographic acetate sheeting." Each sheet must be large enough to include all detail within the strip and extend sufficiently far to permit the matching of the grid intersections with those of adjacent sheets. Sheets are laid out roughly parallel to the flight lines, with proper grid orientation and numbering of the lines established through reference to the photo index. If only a small number of sheets is required, the grid may be constructed individually on each sheet. Frequently, however, greater efficiency will be attained by constructing one master grid and then tracing the others, varying the numbering and orientation as required by the individual sheets. Extreme care must be taken in this tracing operation to avoid serious drafting and parallax errors. After the grid has been drawn, the Shoran points corresponding to each photograph of the strip are plotted and the plotting is checked by a separate draftsman. The sheet is then ready for use by the multiplex operator.

3. Strip Orientation. Since the recovery of true photo plumb points is of great importance in scaling to Shoran control, prime consideration must be given to establishing correct multiplex projector tilts. It is also necessary that the photography be set in strips of several models so as to enable scaling to the best mean fit of several points. Parallax must be carefully removed and all models "tied together" by bringing common pass points to the same elevation reading. In areas where sufficient vertical control is available, the unit is strip-leveled by reference to points in each corner. Otherwise, leveling is accomplished through the use of cross flight photography and the BZ curve method discussed in Chapter VII.

When proper strip orientation has been established and the BZ curve drawn, points to which the strip is to be scaled are plotted by laying off the distance between true and indicated projector plumb points along a line parallel to the line of flight (Chapter VII). The strip is then scaled so as to obtain the best average fit of indicated plumb points to their corresponding modified Shoran positions. Several trials are often necessary before the best average fit is realized.

Pass points common to adjacent flights are next picked along the ends and sides of the strip. As later steps require the orientation of individual models for detail compilation, care must be taken to spot at least four horizontal points per model. If ground vertical control is unavailable, it will also be necessary to pick sufficient vertical pass points to permit releveling of the separate models. The elevation of vertical points, of course, must be corrected for slope of the BZ curve.

4. Adjustment of Strips to a Common Datum. It will usually be found that the positions of common pass points as plotted from

adjacent strip units will fail to coincide perfectly when the sheets are matched along the grid lines. Adjustment of the units so as to remove these inconsistencies will facilitate plotting operations and also help to average out further some of the random Shoran error. This step is accomplished through the preparation of a sketch similar to that shown in Fig. 8-1. Here the discrepancies between units, as indicated by the pass points, are shown to some convenient scale and used as a guide to indicate where slight movement or rotation of some of the units would tend to improve the over-all continuity of the map. The sketch is prepared on cross-section paper and arranged so that the line separation is equal to some even unit of pass point discrepancy. The use of 10 by 10 to the inch cross-section paper with a scale of 1 mm on the map equal to 0.1 inch on the graph paper will prove satisfactory. The rectangular areas representing the strip units are not, of course, shown to the same scale.

The adjustment is made by moving the pass points on the plotting sheets after a study of the working sketch has indicated the proper amount and direction. For example, in Fig. 8-1 the pass points in the unit containing exposures 21 through 25 should be moved so as to correspond both to a clockwise rotation and to a movement of the entire unit to the right. Every point in the strip must be moved so that, in effect, the net result represents

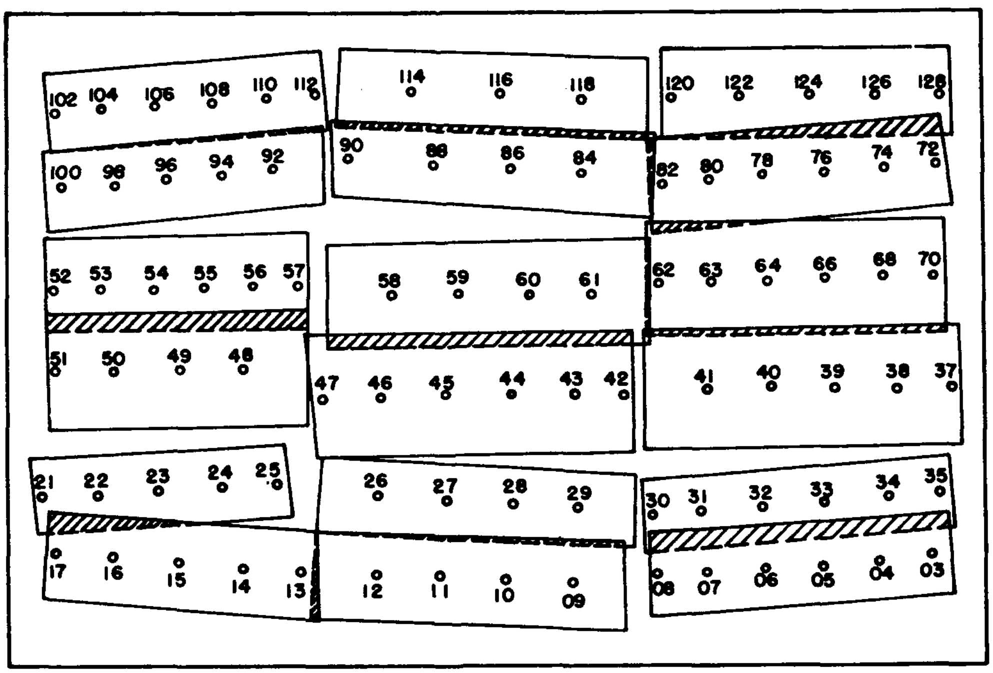

FIG. 8-1. NON-UNIFORMITY OF OVER-ALL DETAIL ORIENTATION AS INDICATED BY PASS POINTS PICKED FROM ADJACENT STRIP UNITS.

only a shift of the area with respect to the grid lines. Next, the pass points in the unit containing exposures 48 through 51 are moved so as to introduce a slight downward displacement and the unit with exposures 52 through 57 is moved slightly upward. Finally, the strips having exposures 92 through 100 and exposures 102 through 112 are given a small clockwise rotation in order to bring the left hand one-third of the total area into coincidence. Pass points in the center and right-hand thirds are then adjusted in a somewhat similar manner so as to produce the desired uniformity throughout the entire area. Occasionally, as in exposures 114 through 118, a scale adjustment within one unit may be indicated. At other times the agreement between strips may be such that no manipulation of the pass points will be required.

The actual adjustment procedure followed in any particular area is somewhat arbitrary and depends upon the skill and experience of the operator. Different operators will not necessarily produce identical results. However, experience has shown that the resulting improvement in position agreement between adjacent models definitely increases the ease with which compilation can be performed and produces improved accuracy in the final map.

5. Plotting. Multiplex detail plotting of the Shoran-controlled map is no different from that of other type maps. Sometimes, the models will be drawn individually using sheets on which the adjusted control has been traced. At other times, the sheets used during the scaling operation will be supplied. Where contours or form lines are to be drawn, the models are leveled either to ground control or to the pass points obtained by the BZ curve method outlined in paragraph 7 of this chapter.

6. Preparation of the Geographic Graticule. The geographic graticule normally will be added to the map manuscript after compilation has been completed and prior to reproduction operations. Line spacing depends upon map scale. Usually, each five or ten minute line of latitude and longitude will be shown. Where ground station positions were known and the UTM grid was used for plotting the Shoran control, this is accomplished by computing and plotting the grid coordinates of appropriate intersection points and then connecting the points with straight lines. Occasionally, where later survey operations have positioned the ground stations, it will be possible to add a geographic graticule to maps originally compiled on the Shoran grid. The procedure needed to compute the coordinates of even intersection points under these circumstances is covered in paragraph 11, Chapter V.

Several errors in the Shoran system tend to introduce a mean error in the positions established on any one mission and, in effect, cause a shift of the entire area with respect to the grid.

If, however, one or more identifiable points of horizontal control are available within the area, the greater part of this error can be removed by redrawing the grid in a slightly displaced location. During map compilation, the model positions of all control points are spotted and their coordinates are scaled from the multiplex sheets. The mean displacement of these multiplex positions from their corresponding true locations as tabulated in trig lists, can then be used as a correction for redrawing the map grid.

7. Use of BZ Curve in Plotting Topography. In most photogrammetric mapping at scales of 1:100,000 and larger, an effort will be made to show the topography. Although Shoran control provides horizontal position only, some of the methods used in establishing correct projector tilt will prove useful in establishing the model orientation required for contouring or form lining in areas where ground vertical control is scarce or even non-existent. Orientation in this manner does not produce the accuracy attainable from ground points but does permit at least approximate contouring of areas in which it proves impossible to perform ground surveying. At least one point of known elevation is highly desirable so as to establish a proper datum.

The procedures to be used require cross flight photography and application of the BZ curve method discussed in Chapter VII. The actual multiplex operations connected with vertical bridging are performed at the same time that horizontal scale is being established. For explanatory purposes, let it be assumed that contours are to be drawn in an area covered by the photography illustrated in Fig. 4-1. The only point of known elevation in the area is assumed to be located near the intersection of flights 6 and 8. Flight 8 is first set in the multiplex and leveled in the line of flight direction by the BZ curve method. If possible, the strip is leveled in the tilt (Y) direction through reference to terrain features; otherwise, a portion of one or more of the flights at right angles must be set first to provide the necessary control. In either case, once flight 8 has been oriented correctly a line of elevations can be established along the center line using the known point as an index and applying the corrections indicated by the shape of the BZ curve. (Flights 7 and 8 can be set in two sections if the required number of projectors is excessive, although orientation as single units is desirable.) The portion of flight 1 between flights 7 and 8 is next oriented by the BZ curve method and elevations are established by indexing from the vertical pass points previously read from flight 8 at its intersection with flight 1. These elevations from flight 8 also supply the information needed for approximate leveling of the strip in the tilt direction. Flight 7 and the necessary portion of flight 6 are then set in turn so as to carry the "vertical traverse" back to the starting point of known elevation. Any error of closure is assumed to be caused by a constant slope along the center lines. Each point can then be corrected by an amount equal to the error of closure times the ratio of distance from the starting point to the total distance around the loop.

The portions of flights 1 through 6 between flights 7 and 8 can now be oriented in both directions. Each strip is leveled in the tip (X) direction with the BZ curve and in the tilt (Y) direction by reference to elevations from the cross flights. Using the cross flight elevations as an index, vertical pass points common to adjacent flights are established in each corner of each model. Once again, of course, corrections for the shape of the BZ curve are applied as though the points were projected onto the center line. Since pass point elevations will probably not read the same from different strips, both readings should be recorded and appropriate notations made as to the strip from which each was taken.

Finally, pass points throughout the entire area are examined for any indication as to possible adjustments that can be made to improve the over-all agreement. In some instances discrepancies in readings from adjacent flights may indicate slight errors in the way one flight was leveled in tip or tilt. At other times, it may be noted that nearly all readings from one flight are too high or too low. Where possible, the discrepancies are eliminated by adjusting the readings. Of course, the goal is to produce an adjustment such that, if all flights were to be reset, each point would read the same elevation in any model in which it appeared. This ideal will seldom be achieved and therefore a certain amount of averaging will be necessary on some of the points. The final adjusted points are then used as level points when the models are individually reset and the contours delineated.

The previous discussion has covered the establishment of vertical pass points for only the right-hand portion of the area portrayed in Fig. 4-1. Control of the left-hand portion is established by repeating the procedure with the appropriate exposures.

8. Map Accuracy. Multiplex maps compiled from Shoran area coverage photography may contain both systematic and random errors. The magnitude of these errors is constantly being reduced as a result of instrument refinements and the development of improved techniques of calibration and adjustment. Shoran tests run in 1946 indicated that, with carefully calibrated equipment, the mean shift of any map sheet could be held to less than 50 feet, regardless of the distance between the area mapped and the controlling ground stations. Actually, a 50-foot displacement of a map sheet that is 150 miles from the nearest control represents a proportional error of only 1 part in 15,800. Also, the nature of the error is such that adjacent map sheets are displaced approximately the same in

both distance and direction and so no significant mis-matching of detail between sheet borders is introduced. Although no recent Shoran photography has been tested, there is little doubt but that present day equipment will give still better results. It should be noted that the availability of occasional identifiable ground control points throughout the area being mapped would permit the sheets to be slipped into position and thus eliminate even these small errors.

Random errors in the Shoran system introduce localized scale and azimuth errors within the map. The 1946 test photography indicated that Shoran-controlled coverage from 20,000 feet could produce maps with relative errors of no more than 105 feet on 90 percent of the well-defined detail points. This would meet peacetime accuracy requirements for inch-to-the-mile mapping but falls a little short of the 1:50,000 scale map standards which call for 90 percent of the features to be located within 83 feet. Since the major source of random error in the Shoran equipment is thought to result from the inability of the airborne operator to maintain perfect pip alinement, improved accuracy will depend largely upon the availability of some type of error meter (Chapter I, paragraph 5 and Chapter IV, paragraph 3). Instrument error is only part of the problem, however. A second source of random error is introduced during multiplex operations by failure to recover exact camera orientation and, therefore, inability to select true photo nadir points. Present plotting methods average out these random errors somewhat by scaling several multiplex models as a unit to corresponding Shoran control. Nevertheless, the relationship between photo tilt and horizontal map accuracy is one of the most important considerations in the entire mapping procedure. Since Shoran appears especially adaptable to the mapping of remote, uncontrolled areas, proper nadir point recovery usually is one of the biggest problems. In such instances, the obtaining of cross flight photography and careful application of the BZ curve method are essential. The limiting factor in Shoran map accuracy may well prove to be dependent upon the accuracy with which camera orientation can be recovered.

CHAPTER IX

SLOTTED TEMPLET MAPPING

CHAPTER IX

SLOTTED TEMPLET MAPPING

1. General. Shoran-controlled area coverage or cross flight photography seldom will be obtained specifically for mapping by the slotted templet method. This type of coverage ordinarily will be used for producing maximum possible accuracy in areas where adequate ground control is not available. For this reason, it usually is intended that the resulting network of photogrammetric control will be established by multiplex procedures. The slotted templet expedient may prove valuable in preparing hasty maps while awaiting the slower but more accurate multiplex results.

In slotted templet mapping, as with multiplex, the most satisfactory solution results from obtaining the best average fit of all photographs to their corresponding Shoran positions. The floating stud holder (Fig. 9-1) provides a simple method of obtaining this desired mean fit. It consists of a circular metal frame, about 2 inches in diameter, with four coil springs attached and extending inward to a central washer. Three pins are fastened to the under side of the frame and serve to hold it rigidly to the base

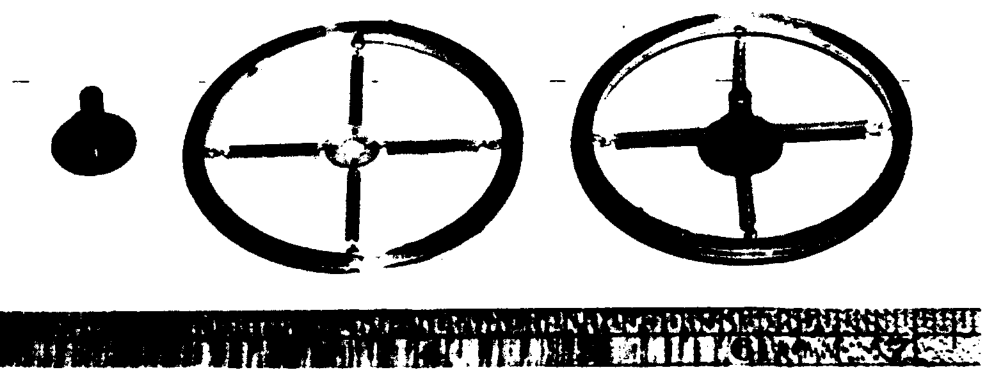

FIG. 9-1. THE FLOATING STUD HOLDER.

grid. The central washer fits over a standard slotted templet stud and permits a movement of about 4 mm in any direction. The use of one holder at each Shoran position allows the entire assembly to adjust automatically to the mean fit of all points.

Although Shoran positions are effective at the nadir points, experience has shown that photo principal points may be used as radial centers when working with good quality mapping photography. This type photography usually contains tilts of no more than a few degrees and, since the resulting displacement of nadir from principal points is of a random nature, the floating stud holders tend to average out the tilt errors together with those of the Shoran positions. Unless tilts can be recovered to within about 10 to 15 minutes or unless the photography to be assembled contains tilts of over 5°, there is no advantage to be gained in attempting to recover the nadir points.

If Shoran photography contains large or constant tilts, a considerable reduction in accuracy must be expected. Constant tilts, such as those resulting from a fixed camera installation that has not been perfectly set for aircraft attitude, are somewhat compensated if adjacent flight lines have been flown in opposite directions. In such instances, the principal points on all photos in one flight will be displaced from the nadir by the same amount and direction. On the adjoining flight, displacements will be in the opposite direction and so the errors will tend to balance out when two or more flights are laid together. Occasionally large random tilts, if not detected from the manner in which prints fit into the photo index, will be spotted during the templet assembly. Templets made from these prints will introduce unusually large displacements of the floating stud holders from their neutral position. If this occurs, the holder (or holders) in question should be removed and the principal point considered only as a pass point.

2. Preparation of Base Sheets. Slotted templet base sheets for area coverage photography are prepared in much the same manner as that described for multiplex mapping. The grid is laid out to the approximate scale of the templets and with a line spacing of from four to six inches. Proper orientation can be established by reference to a photo index on which the grid has been drawn. In many cases, a single base sheet will be sufficient to cover the area under consideration. However, where the assembly is large it can be broken into several sections of about 100 templets each (six or eight flights of ten to twelve exposures). Since control is available for each photo, there is no need to assemble the templets in very large groups.

Once the grid has been constructed, the position of each Shoran point is plotted and the appropriate exposure number is noted.

A standard slotted templet stud is then placed over each plotted point and temporarily held in place by driving a pin through the center of the shaft and into the base board. The floating stud holders are placed in position by slipping their central washers over the templet studs and pressing the pins into the base, care being taken to prevent introducing any tension in the springs. (Standard Corps of Engineers nomenclature for this item is "Stud Holder, floating control point, spring centered, for slotted templet studs.") Several light hammer taps around the outside ring will assure a firm seating of the stud holder. When the straight pins holding the standard studs have been removed, the sheet is ready for assembly of the templets.

Maximum slotted templet accuracy results from using each Shoran point in the area. However, when accuracy can be sacrificed to speed, the assemblies can be laid using every other point or even every third point in alternate flights. For very rough work, two or three points in each corner and a like number near the center of each area of 100 photos will be adequate. This reduction of the number of points used saves considerable computation and plotting time.

3. Preparation and Assembly of Templets. In all slotted templet mapping the greatest accuracy probably results when templets are prepared from prints that are about 15 inches square. This requires an enlargement of about 1.5 diameters over the usual 9- by 9-inch negative size. Tests indicate that, where Shoran control is available for every exposure of 20,000-foot, T-5 photography, assemblies of templets that have been enlarged about 1.5 diameters will have an internal accuracy of about 175 feet or less on 90 percent of the well-defined features. Similar tests using templets prepared from contact prints (9- by 9-inch) yielded a relative map accuracy of approximately 210 feet. These accuracy figures are all exclusive of a mean map position error which can amount to as much as 50 feet as a result of Shoran equipment error plus an additional amount, possible 50 feet or more, from inaccuracies in the slotted templet system. It can be seen, that where a photographic enlarger is available to the mapping unit, the templets for Shoran-controlled assemblies should be prepared from enlargements.

Photographic prints should be made on double-weight paper and processed so as to keep distortion to a minimum. The spotting of principal points from opposite fiducial marks and the selection and transferring of auxiliary tie points around the edges of the prints is accomplished in the same manner as for normal slotted templet work. With enlarged prints, however, a few more than the usual nine points per picture can be selected, provided none are chosen so near the centers that the studs will bind against the rim of the stud holders during assembly. Any existing horizontal positions are also selected and marked, although they are not held rigidly during the assembly.

Templets are prepared from 3-ply bristol board, or other suitable material, by placing the marked prints on top and pricking the point positions through to the blank templets. All pricked points are circled as an aid in recovery and the principal points are labeled to correspond to photo numbers. Center points can then be punched and the wing points slotted using the standard Army equipment supplied for the purpose. The procedures followed in laying the templets should be those described in TM 5-240, modified to include floating stud holders and enlarged templets. It is necessary that care be taken to avoid damaging the slots and that the assembly be tapped from time to time to eliminate possible binding between templets. Fig. 9-2 shows a typical slotted templet laydown being prepared. After completion, all stud positions are marked to provide a control network for use in map compilation by any of the several possible methods.

4. Finishing. Where occasional ground control points are available within the mapped area, a slight improvement in absolute position can be obtained by shifting the grid in the manner that is described for multiplex maps (Chapter VIII, paragraph 6). Also, it must be remembered during compilation and final drafting that any map detail at, or near, existing control points should agree with the descriptions of the stations. Because of random errors throughout the mapping process, this desirable condition may require special attention. After compilation has been completed, all control points that are to be shown on the final map are carefully plotted from their known coordinates. Detail in the neighborhood of these points can then be shifted to conform to true ground conditions. The required movement usually is small but the results will greatly enhance the appearance of the published map.

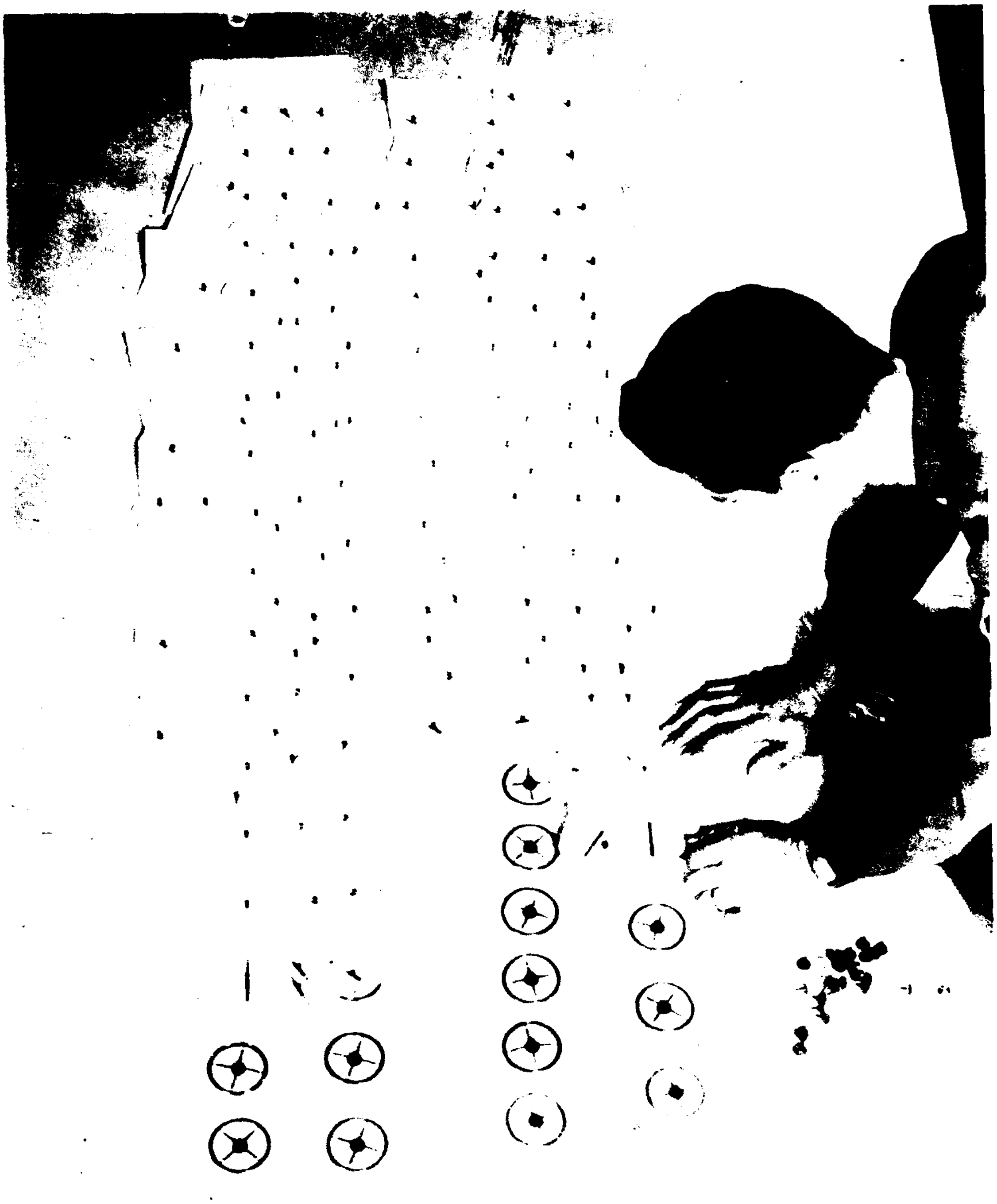

FIG. 9-2. SHORAN-CONTROLLED SLOTTED TEMPLET ASSEMBLY USING FLOATING STUD HOLDERS.

CHAPTER X

PHOTOMAPS

CHAPTER X

PHOTOMAPS

1. General. This chapter deals primarily with the special techniques required in applying Shoran control to mosaicking. The detailed procedures needed in the actual preparation and assembling of photographs is covered in TM 5-240. Shoran points may be used to provide over-all scale and position to otherwise uncontrolled mosaics, and to prepare both semi-controlled and controlled mosaics. The particular method to be employed will depend largely upon the accuracy requirements of the finished map and upon the time available for its preparation. Because of the speed with which they can be produced, uncontrolled and semi-controlled mosaics are used extensively during wartime. Fully controlled mosaics, however, require about as much time to prepare as do complete planimetric maps and so they are of military value only in special cases. The ability to indicate absolute position through the delineation of a graticule on the finished photomaps assumes, of course, that the geographic positions of the Shoran ground stations are known.

2. Establishing Scale and Position of Uncontrolled Mosaics. The fastest method of preparing photomaps is to orient and assemble the photographs by simply matching detail in the overlapping area common to adjacent prints. Although such mosaics often contain serious scale and azimuth errors, the speed with which they can be prepared makes them valuable expedients in many tactical situations. Normally, the determination of absolute scale and position has been dependent upon the recovery of identifiable ground positions. Without ground control, absolute position was unobtainable, although scale could be determined roughly from the focal length of the aerial camera and barometric altimeter readings of flying height. The availability of Shoran positions permits fairly reliable recovery of absolute scale and position without materially increasing the production time.

Scale is established by comparing the distances between Shoran points on the completed mosaic assembly with the equivalent ground distances. Prior to assembling the mosaic, principal points of photos near each corner of the area are pricked and circled with a grease pencil as an aid in later recovery. (The grease marks are easily removed after they have served their purpose.) The mosaic is then prepared in accordance with the instructions given in TM 5-240. Upon completion of the assembly, the diagonals of the figure formed by the selected principal points are carefully measured. The corresponding ground lengths are computed from the following formula:

$$D = \sqrt{(N_1 - N_2)^2 + (E_1 - E_2)^2}$$

where
D = Grid distance
N_1, E_1 = UTM coordinates of point 1
N_2, E_2 = UTM coordinates of point 2

If ground station positions are unknown and UTM coordinates cannot be established, ground distance can be determined by substituting Shoran grid coordinates in the equation just given. Fig. 10-1 illustrates the scale check lines used in the determination. The average of the values determined for each of the two lines is taken as the over-all mosaic scale.

Absolute position is established by adding a UTM grid and graticule to the finished mosaic. As the first step, a UTM grid is laid out on a sheet of translucent acetate to the over-all mosaic scale. After the four corner points have been plotted, this acetate sheet is placed over the mosaic and oriented by superimposing over the photo points. If simultaneous coincidence cannot be obtained on all four points, the sheet is adjusted so as to distribute the error equally. A mechanical mean fit can be obtained by punching holes of the proper diameter in the acetate sheet at the plotted positions and mounting floating stud holders directly over the points on the mosaic. In most cases, however, the best mean fit can be estimated with sufficient accuracy by a visual examination of the discrepancy at each of the four points. After adjustment, the grid intersection points are pricked through to the base and connected with ink lines directly on the face of the photomap.

3. Semi-controlled Mosaics. Semi-controlled mosaics require more time to assemble than do the uncontrolled type but offer a considerable improvement in accuracy. Contact prints matched in density and tonal range are employed in all cases with Shoran points used to position the principal points of each of the photos. The first step of the operation, therefore, will be to compute the coordinates of each photograph to be used and to plot these points on a grid laid out to the average scale of the photography. Thereafter, the photographs are assembled by placing the principal points approximately over their Shoran positions and rotating to get the best average match with adjacent prints. No effort is made to hold exactly to the plotted points because of the possibility of random Shoran and tilt displacement errors. Instead, the dry prints are laid out in small groups ahead of the actual assembly and adjusted so as to obtain an average fit of principal points to corresponding Shoran positions.

The average scale of the photography is established by laying out two or three trial strips and comparing the distances between end principal points with corresponding ground distances as

FIG. 10-1. UNCONTROLLED MOSAIC SCALE CHECK LINES.

determined from the grid coordinates. Photographs in each strip are assembled by carefully matching detail in the overlapping portions and are temporarily held together with drafting tape or staples so as to permit re-use during the mosaic assembly. Ground distances are determined by the formula given in paragraph 2 of this chapter. The mean of all determinations is the scale to be used in constructing the grid.

The grid and the Shoran positions are plotted directly on the rigid board (masonite or plywood) that is to become the mount for the mosaic. Lines are spaced at some convenient plotting interval and the entire grid is oriented so as to assure proper centering of the finished assembly. Although the greater portion of the lines will be covered by the assembled photos, it is important that they be extended sufficiently to permit their recovery around the edges. A straight edge can then be used as a guide in redrawing the missing portions prior to final publication.

A second type of semi-controlled mosaic can be constructed by using the slotted templet method to exactly locate the grid positions corresponding to photo principal points. Here, a templet assembly, made by the procedures outlined in Chapter IX, is used to provide the adjustment to the best mean fit of the Shoran points. Principal points can then be pricked directly onto the mount and held rigidly when the prints are assembled. Even though the method produces improved accuracy and requires less guesswork, considerable extra time is involved in preparing the templet assembly.

4. Preparation of Controlled Mosaics. The use of Shoran in preparing controlled mosaics differs from the conventional method only in that Shoran positions are used to control the slotted templet assembly. In most instances, the rigid mosaic mount serves as the base on which to construct the grid and prepare the templet laydown. Floating stud holders at each Shoran point provide the adjustment to the best mean fit. Both principal points and points around the edges of the prints are located and used to establish the amount of ratioing and rectifying necessary in each of the photographs. Chapter IX explains the use of the slotted templet method with Shoran-controlled photography. The procedures to be employed in ratioing and assembling the prints for a controlled mosaic are covered in TM 5-240.

CHAPTER XI

CONTROL POINT PHOTOGRAPHY

CHAPTER XI

CONTROL POINT PHOTOGRAPHY

1. General. Shoran control point photography is particularly suited to the establishment of the rather widely separated ground positions needed to control small-scale maps or charts. Each mission of two intersecting flights locates a single control point which then can be employed in the same manner as positions determined by astronomic observations or ground surveying. In fact, the method is very effective in supplementing existing ground control that is too widely scattered to meet even charting requirements. Once established, the positions form the control network for reconnaissance mapping from either vertical or trimetrogon photography. Photogrammetric bridging with the basic, over-all coverage usually is accomplished with slotted cards or the mechanical templet set. Scattered control of this type will not normally be satisfactory for multiplex bridging methods.

Fig. 11-1 illustrates a typical photo index of the Shoran-controlled coverage over one point. The actual scaling of the photography and subsequent spotting of the control point may be accomplished by either multiplex or slotted templet methods.

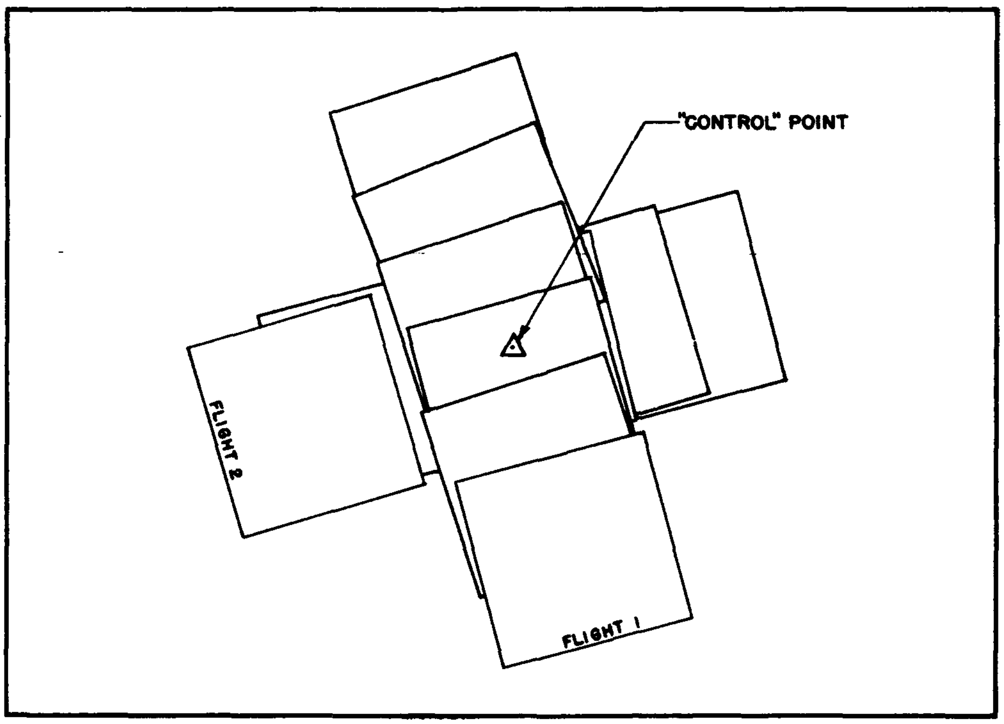

FIG. 11-1. TYPICAL SHORAN CONTROL POINT PHOTOGRAPHY.

Tests indicate possible errors of as much as 150 feet even when multiplex equipment is used. Slotted templet methods will furnish still less accuracy and, primarily because of the inability to recover photo tilts, they may introduce position errors of 200 to 250 feet. However, where maps of 1:250,000 scale and smaller are involved, these errors often are relatively unimportant. The present chapter deals only with the positioning of control points from the Shoran-controlled photography. Photogrammetric bridging and detail compilation procedures using the basic mapping coverage are explained in TM 5-240 and other publications related to mapping.

2. Control Point Recovery by Multiplex Methods. The preparation of work sheets and orientation of multiplex strip units for use with control point photography involve procedures very similar to those discussed in Chapter VIII, Multiplex Mapping. Grid positions of the points corresponding to each photograph should be computed and plotted on sheets that have been laid out at a scale consistent with the aircraft flying height. The multiplex procedure consists of orienting each flight separately to the Shoran control and then determining the position of the point in question. The computed mean of the two positions is assumed to be the true location of the control point. In areas where vertical control is plentiful, each flight can be leveled as a unit using the known elevations. The BZ curve method provides the displacement between true and indicated nadir points. Generally, however, elevations will not be known and so the BZ curve method must also be used for strip orientation.

The necessary procedure is best understood by reference to Fig. 11-1. Flight 1 is set in the multiplex, brought to approximate scale, and carefully leveled by means of the BZ curve (Chapter VII). This permits a series of relative elevations to be established along the center line. Flight 2 can then be set and scaled to the Shoran control. The BZ curve is used both for leveling in the line-of-flight direction and for indicating the displacement of nadir points resulting from false tip. The strip is leveled in the tilt direction by reference to the relative elevations obtained from flight 1. The control point is plotted and its coordinates are scaled from the plotting sheet. Also, with the orientation thus fixed, a line of relative elevations is read along the center line. Finally, flight 1 is reset and leveled using the relative elevations from flight 2 and the BZ curve. The strip is then scaled to the Shoran points and a second position is obtained. Coordinates of the two positions are averaged to obtain the final location.

3. Control Point Recovery by Slotted Templet Methods. The use of slotted templet procedures in recovering control point position involves nothing more than assembling the two flights as a unit and scaling to the plotted Shoran points. The feature to be

located is selected as an auxiliary point during preparation of the templets so that its position becomes fixed upon completion of the assembly. Contact size photographs and templets will normally be satisfactory since any improvement in accuracy resulting from the use of enlargements seldom will be significant in the type mapping for which the control point method is applicable. Wing points are selected and templets are prepared in the regular fashion, using principal points as radial centers. Care must be taken not to select too many points in the area of overlap between flights, since excessive slots tend to weaken the templets and thus decrease accuracy. The best average fit of the assembly to the Shoran control is obtained by placing a floating stud holder at each Shoran point. After all templets have been assembled, the target point is marked and its coordinates are scaled from the work sheet.

CHAPTER XII

SHORAN CONTROL FOR EXISTING UNCONTROLLED PHOTOGRAPHY

CHAPTER XII

SHORAN CONTROL FOR EXISTING UNCONTROLLED PHOTOGRAPHY

1. General. Occasions may arise when it will be desirable to use Shoran-controlled cross flights in conjunction with existing uncontrolled photography. Although the resulting map accuracy will not equal that to be expected from complete Shoran-controlled photographic coverage, considerable flying time can be saved if reduced standards can be tolerated. The necessary Shoran photography consists of cross flights normal to, and spaced at, intervals of about each six or seven exposures along the existing coverage (Chapter IV). The controlled flights then can be scaled to the Shoran positions and used to spot lines of pass points between which the uncontrolled exposures are bridged.

Multiplex methods normally will be employed so as to obtain maximum position accuracy from the cross flights. This involves the recovery of camera orientation so that photo nadir points can be scaled to the Shoran control. Where ground vertical points are unavailable, the BZ curve method described in Chapter VII is employed. Altimeter readings will accompany the Shoran photography and can be used to level each control strip in line of flight. Occasionally, leveling in the tilt (Y) direction can be accomplished from lines of correct relative elevations established by the BZ curve method and using the existing photography. However, if the needed altimeter readings are not available with the uncontrolled coverage, separate auxiliary strips are required for use in tilt leveling of the cross flights. Fig. 12-1 illustrates a typical flight plan where the auxiliary strips are included. It should be noted that the auxiliaries need not be Shoran-controlled, although it is important that accurate altimeter readings be available for each exposure. Multiplex tests with cross flight photography from 20,000 feet indicate that maps having an internal accuracy of approximately 125 feet or less on 90 percent of the well-defined features can be prepared. This accuracy is exclusive of the mean map position error.

2. Multiplex Methods for Cross Flight Photography. Orientation of the Shoran-controlled cross flights is identical to the procedure used with area coverage photography. Work sheets are laid out roughly parallel to the line of flight using either the Shoran or UTM grid, depending upon the coordinate system in which the Shoran positions have been computed. The photography is set in strips of five to seven models so as to permit multiplex scaling to the best average fit of several points. In areas where vertical control is available, the units are strip-leveled by reference to

appropriate ground points; otherwise, the BZ curve method described in Chapter VII is used. Relative elevations at right angles to the cross flights are established by application of the BZ curve method to the auxiliary flights. Once the control strip has been oriented, the corrections for false tip are applied to indicated nadir points and the entire unit is scaled to the best mean fit of the Shoran positions. Horizontal pass points to be used as control for the mapping photography can then be spotted throughout the strip in sufficient density to assure the appearance of three or four points in each of the mapping flights. The points selected should be such readily identifiable features as road intersections, corners of large buildings, and the like. It is good practice to actually draw a portion of the features and to write out detailed descriptions directly on the work sheet.

Sometimes the cross flights and auxiliaries are used to establish a framework of vertical points from which approximate contours or form lines can be delineated. This procedure requires application of the vertical traverse (paragraph 7, Chapter VIII). In this way elevation points, as well as positions, are spotted along the cross flights and used as a guide in strip-leveling the uncontrolled photography. Though the method cannot be relied upon to provide very good vertical accuracy, conditions may arise where no other alternative is available.

Once the pass points have been picked, multiplex orientation and bridging with the mapping photography are accomplished in accordance with TM 5-244. Individual sheets for each flight usually are laid out on a transparent medium to facilitate point transferring from the Shoran work sheets and must, of course, use the same grid system. The addition of a geographic graticule to manuscripts compiled on the Shoran grid is explained in paragraph 6, Chapter VIII.

3. Slotted Templet Methods. The use of Shoran points to control slotted templet mapping is covered in Chapter IX. Where perimeter photography is used, base sheets are made large enough to accommodate sections of about 100 templets from the uncontrolled coverage. In small areas a single base sheet is often sufficient. All appropriate Shoran control is then plotted and floating stud holders are put in place at each of the points. Templets from the cross flights use principal points as radial centers and are assembled over the stud holders so as to obtain a good mean fit. Templets from the mapping photography are prepared in the normal manner, except that pass points from the cross flights are transferred and also used as pass points on the regular coverage. The mapping assembly then is made right over the cross flight templets, using the studs at common points to establish scale. Finally, wing points are pricked through to the base sheet to provide the network for compilation by any desired procedure.

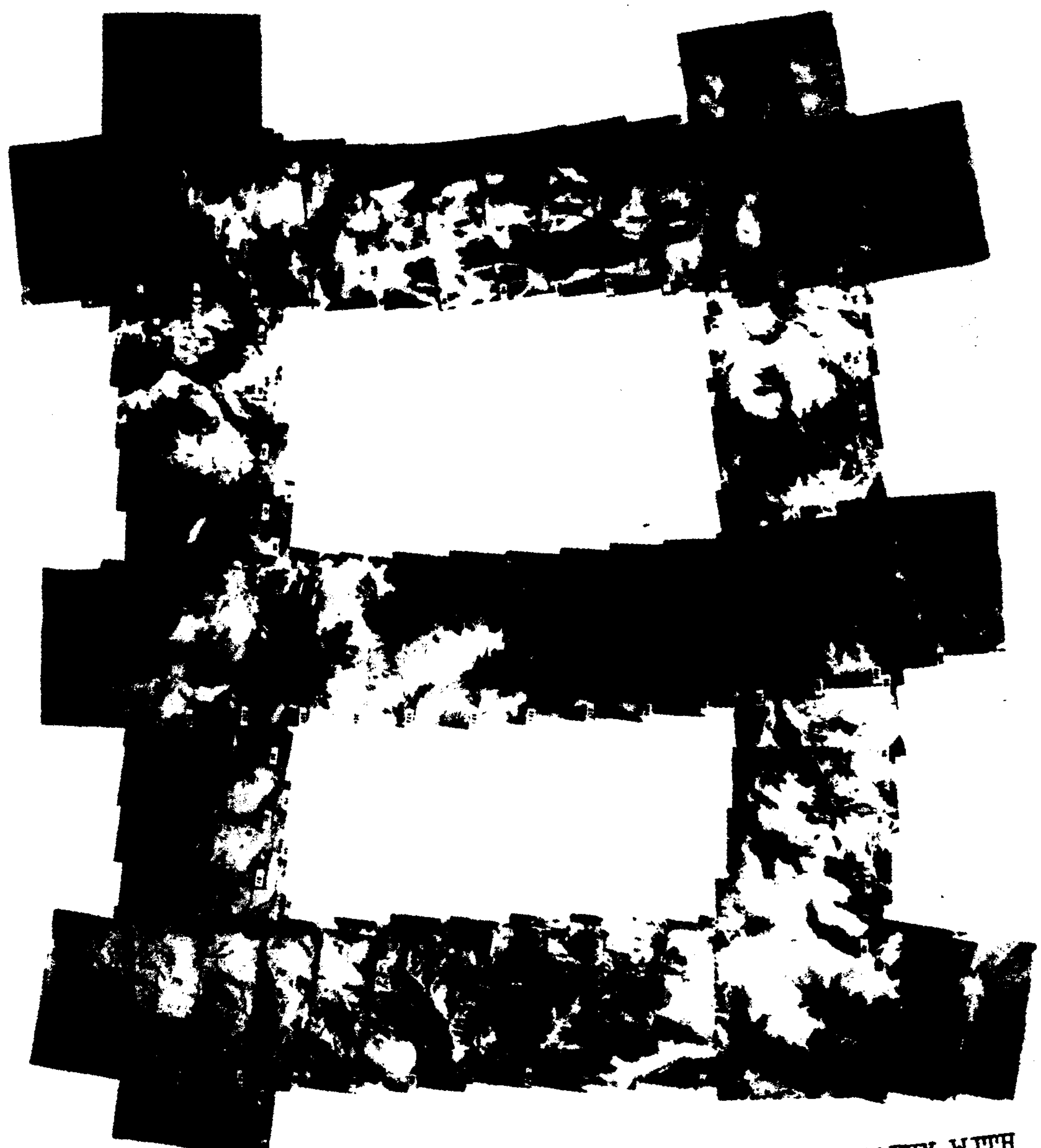

FIG. 12-1. SHORAN-CONTROLLED CROSS FLIGHT PHOTOGRAPHY WITH AUXILIARY STRIPS USED IN RECOVERING CAMERA TILT.

APPENDIX A

GLOSSARY

Altimeter Recording Camera - The modified 35-mm movie camera which photographs a barometric altimeter, radio altimeter, exposure counter, and other auxiliary data at the instant of each aerial camera exposure.

Arc Navigation - A method of Shoran-controlled flight line navigation whereby arcs of constant radii are flown about one of the ground stations.

Area Coverage Photography - Complete photographic coverage of an area by conventional mapping photography having parallel flight lines and stereoscopic overlap between exposures in line of flight. When applied to Shoran, the term implies that recorded Shoran distances are available for each exposure.

BZ Curve - The curve obtained when a smooth line is drawn through points representing the heights and distances along the flight line of the several projectors used in a multiplex extension.

BZ Curve Method - A method utilizing characteristics of the BZ curve for finding the displacement of true photo plumb points from indicated projector plumb points in multiplex strip orientation. The method also provides a means for strip leveling using only the barometric altimeter readings of aircraft flying height.

Cathode-ray Oscilloscope - The tube which presents the sweep circle and Shoran electromagnetic pulses as visual phenomena for use by the airborne operator.

Control Point Photography - Shoran-controlled aerial photography consisting of two short right-angle flights intersecting over a target or secondary control point.

Cross Flight Photography - Single photographic strips having stereoscopic overlap between exposures and having a flight direction at right angles to that of coexistent area coverage photography. When applied to Shoran, the term implies that each of the cross flight exposures is accompanied with recorded Shoran distances.

Distance Recording Camera - The modified 35-mm movie camera which photographs the Shoran distance counters and other auxiliary instruments at the instant of each aerial exposure.

Drift Station - A term sometimes used to designate the ground station about which the aircraft flies during arc navigation.

The second ground station is then referred to as the "Rate" station.

Echo Pips - Pips formed on the airborne cathode-ray tube sweep circle by impulses returning from the ground stations.

Echo Timing - The measurement of time required for a short train of radio waves to travel the round-trip path from an originating station to a reflector, or transponder.

Error Meter - A proposed instrument for furnishing information concerning the accuracy of pip alinement at the instant of each exposure.

False Tip - The angular differences, measured in the vertical plane through the flight line, between the axis of the aerial camera at the instant of each exposure and the axis of corresponding multiplex projectors when oriented in strips.

Floating Stud Holder - A device which permits spring-controlled movement of a standard slotted templet stud about a plotted position. The use of one floating stud at each Shoran position produces an automatic adjustment of the assembly to the best mean fit of all points.

Ground Station Delay - The time (expressed as round-trip distance) required for the Shoran pulse to travel through the circuits of a ground station.

Inverse Computation - Computations connected with the determination of distance and azimuth between two points, the positions of which are given in geographic or plane coordinates.

Marker Pip - The stationary pip formed on the sweep circle by an impulse from the airborne set. This pip marks the point of zero distance and is the standard to which echo pips are alined.

Nadirscope - An instrument for attachment to the multiplex tracing table, which permits recovery of projector nadir points.

Observed Zero - Reading of Shoran mileage counters when the airborne set is receiving its own signal.

Photographic Mission - The taking of a group of consecutively exposed aerial photographs over one area and on the same day.

Pip - A kink or deflection in the otherwise smooth sweep circle caused by the application of an impulse to the cathode-ray oscilloscope.

Precomputed Coordinate Navigation - A little-used method of flight line navigation whereby proper Shoran readings from the air station to each ground station at regular intervals along a straight line are computed before take-off and the aircraft then flown so as to pass, as near as possible, along this precomputed course.

Pulse - A short train, or burst, of radio waves.

Radio Altimeter Carry - A method of "carrying" absolute flying height values from a datum area over which a radio altimeter reading has been taken to another area by means of a barometric altimeter.

Radiosonde - An instrument carried aloft by means of a balloon or dropped from an aircraft by parachute, which measures atmospheric pressure, temperature, and humidity at regular intervals and transmits the readings by means of a small radio sending set.

Rate Station - See Drift Station.

Shoran - An electronic measuring system for indicating distance from an airborne station to each of two ground stations. The term is a contraction of the phrase "SHOrt RAnge Navigation".

Shoran Grid - A rectangular grid with the X-axis through the two Shoran ground stations and using the westernmost station (Station A) as the origin of coordinates.

Shoran Line Crossing - A method of determining distance between two points by flying across the joining line.

Shoran Range - The maximum possible operating distance between Shoran aircraft and ground station as limited by flying height, ground station elevation, terrain, and earth curvature.

Shoran Reduction - The computational process of converting from a Shoran distance reading to an equivalent geodetic distance.

Shoran Triangulation - A method of triangulation in which the sides of appropriate figures are measured by the Shoran line-crossing method.

Shoran Wave Path - The path taken by the Shoran wave as it travels from the airborne to the ground station.

Signal Intensity - Strength of the Shoran signals received at the airborne station. Intensity variations result primarily from ground reflections of the radio waves.

Standard N.A.C.A. Moist Atmosphere - The empirical N.A.C.A. standard atmosphere with added mean annual vapor pressure at about 40° latitude in the United States.

Station A - The usual designation of the westernmost ground station. The easternmost ground station is designated as Station B.

Station Angle - The horizontal angle subtended at the aircraft by the two Shoran ground stations.

Straight Line Indicator - A Shoran navigational device which permits the flying of straight lines at any orientation to the base.

Sweep Circle - The fluorescent ring, appearing on the face of the cathode-ray oscilloscope, that is caused by the rapid circular travel of a tiny spot of light.

Timing Advance System - The system used to produce transmitted pulses sufficiently earlier than the corresponding marker pulses so that a signal returning from its round trip arrives just in time to meet the corresponding pulse at the cathode-ray tube. Correct adjustment of the two timing advance systems in the airborne set is indicated by proper alinement of the two echo pips with the marker pip.

Timing Frequency Error - The error introduced by inability to establish the true oscillator frequency at the instant of Shoran measurements.

Timing Non-linearity Corrections - The corrections made necessary by slight irregularities in the functioning of the 1-mile phase-advancing devices.

Timing Oscillator - The crystal-controlled oscillator used as a standard in the timing of pulse travel. True path distance (exclusive of the velocity correction) in miles is given when the oscillator frequency in cycles per second is equal to one-half the velocity of electromagnetic waves in miles per second (93,109.5).

<u>Velocity Correction</u> - The correction made necessary by the fact that the speed of electromagnetic propagation varies with varying meteorological conditions along the wave path.

APPENDIX B

SAMPLE PHOTOGRAPHIC SPECIFICATIONS

APPENDIX B

SAMPLE PHOTOGRAPHIC SPECIFICATIONS

Specification No. ____
28 September 1949

SPECIFICATIONS
FOR
SHORAN-CONTROLLED AERIAL PHOTOGRAPHY

SPECIFIC PROJECT DATA

Project name:	Fort Sill, Oklahoma
Project location:	Fort Sill, Oklahoma
Camera to be used:	AF type T-5
Area to be photographed:	1416 square miles
Photography to be accomplished:	Between 15 October 1949 and 31 December 1949
Flight altitude above sea level:	21,300 feet
Elevation of mean terrain above sea level:	1,300 feet
Flight direction:	East-west
Flight direction of special flights:	North-south
Number of flight lines:	Five - as shown on flight map
Number of special flight lines:	Four - as shown on flight map
Side lap:	10 percent minimum
Names of geodetic control stations and alternates of geodetic control stations selected:	Gem (Hemphill County, Tex., W. M. 1927). Washita (Roger Mills County, Okla., W.M. 1927) This station is the alternate station for "Gem." Cushing (Payne County, Okla., CIA, 1935).

	Long (Lincoln County, Okla., CIA, 1935). This station is the alternate station for "Cushing."
Delivery date:	1 January 1950
Maps furnished:	Caddo County, Okla., 1:63,360 Kiowa County, Okla., 1:63,360 Comanche County, Okla., 1:63,360 Stephens County, Okla., 1:63,360 Grady County, Okla., 1:63,360 Cotton County, Okla., 1:63,360 Tillman County, Okla., 1:63,360 Oklahoma City (R-5) 1:500,000 scale sectional aeronautical chart
Geodetic control data furnished:	United States Coast and Geodetic Survey publications as follows: Descriptions of Triangulation Stations No. 553, "Ada, Oklahoma to Abiline, Kansas." No. 698, "One Hundredth Meridian Boundary Arc, Texas and Oklahoma." Geographic position cards for Long, 1935, and Cushing, 1935 on Ada, Oklahoma to Abiline, Kansas arc; and Washita, 1927, and Gem, 1927, on Texas-Oklahoma Boundary, 100th meridian arc. Second-order leveling, "Cheyenne, Oklahoma to Brisco, Texas." and Byars, Oklahoma to Arkansas City, Kansas (Okla. portion)."

NOTES

1. The number of flight lines specified above are the minimum number of flights that will cover the area at the altitude specified and provide a side lap of 20 percent between flight lines 1 and 2 and between lines 2 and 3, and 25 percent between 3 and 4 and between 4 and 5 at the mean terrain elevation of 1,300 feet above sea level of the area.

2. The four special flights listed above will be flown in a north-south direction across the project as shown on the flight map.

3. The approximate locations of the geodetic control stations are shown on the 1:500,000 scale sectional aeronautical chart, "Oklahoma City."

4. The second-order leveling data contains descriptions and elevations for the following bench marks: P-49 and Q-50 which are near triangulation station "Cushing"; K-49 and L-49 which are near triangulation station "Long"; 1-103, M-257, and L-257 which are near triangulation stations "Gem" and "Washita."

Specification No. ____
28 September 1949

SPECIFICATIONS
FOR
SHORAN-CONTROLLED AERIAL PHOTOGRAPHY

SECTION I - GENERAL PROVISIONS

1-01. COMPONENT PARTS OF SPECIFICATIONS. These specifications for Shoran-controlled aerial photography are composed of: Section I, General Provisions; Section II, Technical Provisions, Aerial Photography; Section III, Technical Provisions, Shoran; Page 1a, SPECIFIC PROJECT DATA; and the maps and geodetic control data listed on page 1a, SPECIFIC PROJECT DATA. Page 1a is attached to the front of Section I, General Provisions.

1-02. WORK TO BE DONE. The work to be done under these specifications consists of furnishing all services, materials, supplies, and plant, and making such flights as may be necessary to cover completely with Shoran-controlled aerial photographs, suitable for use with Stereophotogrammetric equipment, the area or areas, described in the SPECIFIC PROJECT DATA and shown on the accompanying maps. The organization performing the Shoran-controlled aerial photography will be required to furnish the original aerial negatives, one set of contact glossy prints, a photo plot of all areas photographed, and all Shoran control data and data related thereto required by Section III.

1-03. MAPS AND GEODETIC CONTROL. The maps and geodetic control listed on page 1a, SPECIFIC PROJECT DATA are the only maps and geodetic control which will be supplied for the work to be done. It will be the responsibility of the photographic organization to procure any other such data. This organization will assist in the procurement of such additional data when so requested.

1-04. DELIVERY. The photographic organization shall deliver to this organization, the photographic and Shoran materials and data specified in Sections II and III, immediately after completion of the work as required by these specifications. The photographic organization will make every effort to deliver the following photographic and Shoran materials and data on or before the due date as specified on page 1a, SPECIFIC PROJECT DATA. A copy of the transmittal shall be sent to the U.S. Air Force Central Film Library:

a. Original aerial negatives.
b. Prints of aerial negatives.
c. Photo plots.
d. Shoran distance recording film.
e. Altimeter recording film.

f. Oscilloscope recording film.
g. Manual reading of Shoran distance counters.
h. Data necessary for correlating each aerial exposure with the recording camera exposures.
i. Computed velocity corrections.
j. Ground station delay calibration data.
k. Airborne zero readings.
l. Airborne timing frequency.
m. Timing non-linearity corrections.
n. The horizontal and vertical positions of ground antenna stations.
o. Operational log.
p. Mean flying height of each mission.
q. Identification of ground antenna stations to which recorded distance readings refer.
r. Simultaneous recording of all clocks immediately before and after each mission.

1-05. INSPECTION AND ACCEPTANCE. The materials required by these specifications will be inspected by this organization and the photographic organization will be notified within 14 calendar days after receipt by this organization whether or not they are acceptable. If any part of the project fails to meet the requirements of these specifications, the materials will be returned to the photographic organization and it will be notified of the unacceptable portions which will require correction.

1-06. REFLIGHTS. All reflights necessary to obtain satisfactory results in accordance with the requirements of these specifications, shall be determined and made by the photographic organization.

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28 September 1949

SPECIFICATIONS
FOR
SHORAN-CONTROLLED AERIAL PHOTOGRAPHY

SECTION II - TECHNICAL PROVISIONS
AERIAL PHOTOGRAPHY

2-01. DAYS SUITABLE FOR AERIAL PHOTOGRAPHY. Aerial photographs shall be taken only between the hours when solar altitude is greater than 30° on all days when weather conditions are such that clear, well-defined photographic negatives, as required in paragraph 2-09, can be made. No photographs shall be taken when streams are locally out of their normal banks or when the ground is covered by snow. The photographs shall be taken between or on those dates specified on page 1a, SPECIFIC PROJECT DATA.

2-02. CAMERA TO BE USED.

a. The aerial photographs shall be made with a U.S. Air Force Type T-5 or T-11 camera. The camera shall be maintained in proper working condition and shall be installed in the airplane in a manner and together with such accessories as may be necessary to secure photographs meeting the requirement of these specifications.

b. Only stained glass filters, optically flat and coated with a metallic vignetting correction film, shall be used with the aerial camera.

c. Any disassembly or reassembly of the aerial camera which will affect the calibration constants shall require recalibration of the camera.

d. The camera or cameras and the magazines used on the project shall have performed satisfactorily on a test flight. The negatives exposed on the test flight, or service test, must have been submitted to and approved by this organization.

2-03. FLIGHT ALTITUDE. The aerial negatives shall be exposed at the flight altitude above mean sea level specified in the SPECIFIC PROJECT DATA. The flight altitude for a mission shall be maintained as constant as possible and no exposure within the mission shall deviate more than ±100 feet from the average flight altitude. The average flight altitude for a mission shall not show a departure of more than ±5 percent from the specified flight altitude above mean terrain. The mean terrain elevation for the project is given on page 1a, SPECIFIC PROJECT DATA. The determination of the average flight altitude for each mission shall include all atmospheric and other corrections necessary to assure that the value is the true flight altitude and that it is correct to within 100 feet.

2-04. FLIGHT LINES AND STRIPS.

a. No flight lines will be permitted in addition to that number specified on page 1a, SPECIFIC PROJECT DATA.

b. All flight lines and special flight lines, as specified on page 1a, SPECIFIC PROJECT DATA, shall be Shoran controlled.

c. The flights shall be flown in that direction specified on page 1a, SPECIFIC PROJECT DATA.

d. All flight lines shall be as straight as possible. The mean bearings of adjacent strips shall be within 5° of parallel. In no case shall the lack of parallelism between adjacent photographic strips, or sections thereof, be such as to prevent the side lap between strips from conforming with the requirements of paragraph 2-05. Each flight shall be so photographed that the principal points of the first and the last negatives thereof shall fall outside the boundaries of the specified area in order to assure that every point within the area shall appear on at least two consecutive photographs in the line of flight. All photographs in a flight line shall be continuous, consecutive exposures, the time interval between any two consecutive exposures being no longer than that required to provide the forward lap. Any time interval longer than the normal exposure interval shall require reflights. (See paragraph 2-04e.)

e. When any portion of any flight is rejected, that portion must be covered by a reflight which shall overlap each end of the acceptable portions of that flight by four exposures.

2-05. OVERLAP.

a. Forward lap shall not be less than 53 percent nor more than 60 percent and shall average 56 percent. Any forward lap of less than 53 percent or greater than 60 percent throughout the entire width of the photograph (that dimension of the photograph normal to the flight direction) or strip shall be sufficient grounds for rejection except where the displacement of images in the photograph, caused by abrupt changes in elevation within the area of forward overlap, approaches or exceeds the limiting values given above. Where photographs are taken under such conditions of terrain, there shall be no maximum value for the forward lap provided that, at some point along both the leading and trailing edges of the photographic overlap, normal to the flight direction, there is a point at which the forward lap is between 53 percent and 56 percent. This condition shall be determined by matching identical images on the two overlapping photographs and making the measurements to determine the percentage of lap along the edges of the photographs. It is further provided that computations must show that all forward lap in excess of 60 percent is due to the change in elevation within the area of forward lap. The minimum forward lap of 53 percent is effective in all cases. (See paragraph 2-06.)

b. The minimum side lap between adjacent strips shall not be less than 10 percent. Side lap will be determined after all deductions for crab, relief, tilt, and other factors have been considered. For the purpose of measuring side lap, the only portion of the flight considered is that on which all ground points covered by the flight are imaged on at least two consecutive photographs in the flight.

2-06. CRAB. Crab shall not exceed 10° as measured from the line of flight (the flight path, or "track," of the airplane as indicated by the principal points of the consecutive photographs). In any series of two photographs, the relative crab shall be limited by the conditions of paragraph 2-05a.

2-07. TILT. Tilt shall not exceed 3° for any exposure. The average tilt for a 20-mile section shall not exceed 2° and shall not exceed 1° for the entire job.

2-08. AERIAL FILM. Only topographic base, safety aerial film shall be used. The film shall be of a class that will produce negatives meeting the requirements of these specifications.

2-09. AERIAL NEGATIVES.

a. The shutter speed shall be as short as film, filter, and light conditions permit. In no case shall the ground speed in miles per hour exceed the flight height in thousands of feet divided by five times the shutter speed in seconds.

b. The negatives must be exposed and developed in such a manner that all detail in all of the distinguishable terrain tones from the darkest terrain feature, or shadow, to the highest terrain feature, or highlight, is discernible in the aerial negative. The negatives shall show a minimum density of not less than 0.3 and a maximum density of not more than 1.5 as measured with a densitometer having a scale range of 0 to 3.0. The negatives must be sharp in detail, fine grained, and free of clouds and cloud shadows, light streaks, static marks, or other defects which, in the opinion of this organization, render them unsuitable for their intended purpose.

Each end of the roll shall have a length of clear film equal to at least three exposures.

c. After the film has been processed and dried, the negatives shall not show a differential change in dimensions of more than 0.2 mm nor shall any distortion so introduced render negatives unsuitable for use with the photogrammetric equipment in the opinion of this organization. Usually this condition is limited to those distortions that will not warp the stereo models by more than ±0.15 mm. Differential changes in film dimensions shall be determined by comparing the focal plane dimension as given on the camera calibration report with the dimensions as determined by measuring between the same two points as recorded on the film. Uniform changes in film dimensions are not considered under this provision.

2-10. PROCESSING AND DRYING AERIAL FILM.

a. Special care shall be exercised to insure the proper development and the thorough fixation and washing of all film and to avoid rolling the film tightly on drums or in any way distorting it during processing or drying.

b. If the photographic organization desires to use any special machines for developing or drying the film, it shall demonstrate by tests made with contact prints of suitable grids that the methods of the machine do not introduce distortions in excess of ±0.02 mm.

c. All splices shall be of a permanent nature and the film shall not be trimmed closer than 8 inches from an exposed negative.

2-11. AERIAL FILM ROLLS.

a. All exposures made on the project shall be retained on the film rolls whether such exposures are acceptable or not. A roll of film may be cut only to remove unexposed portions of the film prior to processing or to place different projects into separate pieces of film. In either event, film shall not be trimmed closer than 8 inches from an exposed negative.

b. A roll of film is defined as that length of aerial film exposed in a single magazine on a single project. Each roll of film shall be given a number and these numbers shall start with one and progress consecutively throughout the project.

c. Short rolls of film may be spliced together for spooling, but they shall not lose their identity as separate rolls.

2-12. INDEXING AERIAL EXPOSURES.

a. The aerial negatives shall be numbered and titled as prescribed in the current issue of AF Regulations No. 95-7 and in addition, the aerial negatives shall be identified as "Shoran Controlled." The negative number shall be shown with figures 3/16 inch high placed in the corner of the negative 1/8 inch from the edges of the image area, and shall be of sufficient clarity for easy reading when reduced five times. The remainder of the titling data shall be shown with letters and figures that are as small as possible and placed adjacent to the edge of the image area so as to obscure a minimum of photographic detail.

b. Each roll of film shall have on the clear portion of the film at each end, adjacent to the end exposures, so that it will appear on a slightly oversized print, the following data: type and serial number of the camera; type and serial number of the lens; type and serial number of the cone; type and serial number of the magazine; the project name; the mission number; the roll number; and identity of all corresponding recording camera film.

c. The metal container for each spool of film shall be labeled by affixing a form on which is given all data necessary to identify completely the film contained therein.

d. The photographic agency shall prepare an index of the photography by plotting the photo locations on an overlay keyed to a small-scale map. The photographic index shall identify and tabulate all recording camera film that applies to the aerial photography shown on the index.

e. Where reflights have superseded rejected photography, the rejected photography shall be shown by a dash line and the superseding photography shall be shown in the same manner as other acceptable photography.

2-13. PRINTS. The photographic organization shall prepare one set of single-weight, glossy, contact prints for all exposures made on the project. The prints shall be trimmed to the image edge except that the edge containing the recorded data shall be trimmed just beyond these data. Special care shall be exercised in exposing the prints so that all the recorded data are legible. The prints may be dried as the photographic organization desires.

Specification No. ____
28 September 1949

SPECIFICATIONS
FOR
SHORAN-CONTROLLED AERIAL PHOTOGRAPHY

SECTION III - TECHNICAL PROVISIONS
SHORAN

3-01. INSTALLATION. The error caused by the airborne antennas-camera location relationship shall be less than 3 feet.

3-02. DISTANCE COUNTER READINGS. Manual readings of the distance counters shall be made at the instant of exposure of an aerial negative near the beginning and end of each mission and these values shall be recorded and related to the aerial exposures to which they apply.

3-03. PIP ALINEMENTS. The deviations from the true pip alinements during Shoran operations shall be held to an absolute minimum.

3-04. VELOCITY CORRECTIONS. Velocity corrections shall be computed from meteorological conditions at the time of operations and furnished in the form of tables or curves. Accuracy of the velocity correction shall be such that the Shoran distances may be computed with an accuracy of at least 1 part in 100,000. Each velocity correction shall be identified with the group of aerial photographs to which it applies.

3-05. GROUND STATION DELAY CALIBRATION DATA. Complete ground station delay calibration data shall be recorded and tabulated in terms of round-trip distance time required for the Shoran pulse to travel through the circuits of each ground station.

3-06. AIRBORNE ZERO READINGS. Airborne zero readings shall be recorded at the beginning and end of each mission and whenever Shoran operators are changed.

3-07. AIRBORNE TIMING FREQUENCY. The airborne timing frequency shall be determined with an accuracy of at least 1 part in 100,000.

3-08. TIMING NON-LINEARITY CORRECTIONS. Timing non-linearity corrections shall be furnished in the form of tables or curves.

3-09. SHORAN GROUND ANTENNA STATIONS. The geodetic control stations and alternate stations are as given on page 1a, SPECIFIC PROJECT DATA. The Shoran ground antenna stations shall be located at the geodetic control stations except as noted below. The ground antenna stations may be moved from the location of the geodetic control stations to satisfy the radio reception requirements; such movement shall be held to the minimum consistent with requirements. The horizontal position of the ground antenna stations shall be determined to an accuracy of 1 foot as referred to the nearest geodetic control station. The elevation of the antenna stations shall be determined to within 2 feet as referred to the nearest bench mark. Height of the antenna dipoles above the antenna stations shall be determined to within 2 feet.

3-10. SHORAN OPERATIONAL LOG. A complete operational log shall be kept of all occurrences that might have a bearing on the accuracy of the operations.

3-11. RECORDING CAMERAS.

a. Synchronization. Synchronization of the recording cameras with the aerial camera shall be such that the aircraft shall not have moved more than 3 feet between related exposures. The number appearing on the exposure counter of the aerial camera and on the exposure counters of the recording cameras shall be identical in all cases, or data shall be recorded equating the exposure numbers.

b. Shoran Distance Counter Recorder. The Shoran distance counter recording camera shall also record Greenwich Standard Time, free air temperature, a compass showing the heading of the aircraft, and exposure counter, an altimeter, and a data card. The data card shall correlate the Shoran distance dials with Shoran ground stations, identify the photographic mission to which it applies, and show the date.

c. Altimeter Recorder. The barometric altimeter in the altimeter recorder shall be an Air Force type D-8 or equivalent. The altimeter recorder shall record an exposure counter and may record the time.

d. Oscilloscope Recorder. The oscilloscope recorder shall be used on the project. The oscilloscope recorder shall record an exposure counter and may record the time.

e. Clocks. Data necessary for the synchronization of all clocks photographed shall be recorded. Preferably, this should be done by setting all clocks to within 1 second before the take-off and the simultaneous recording of the time shown by all clocks immediately before and after photographic operations. These data shall identify the devices to which each of the clocks apply.

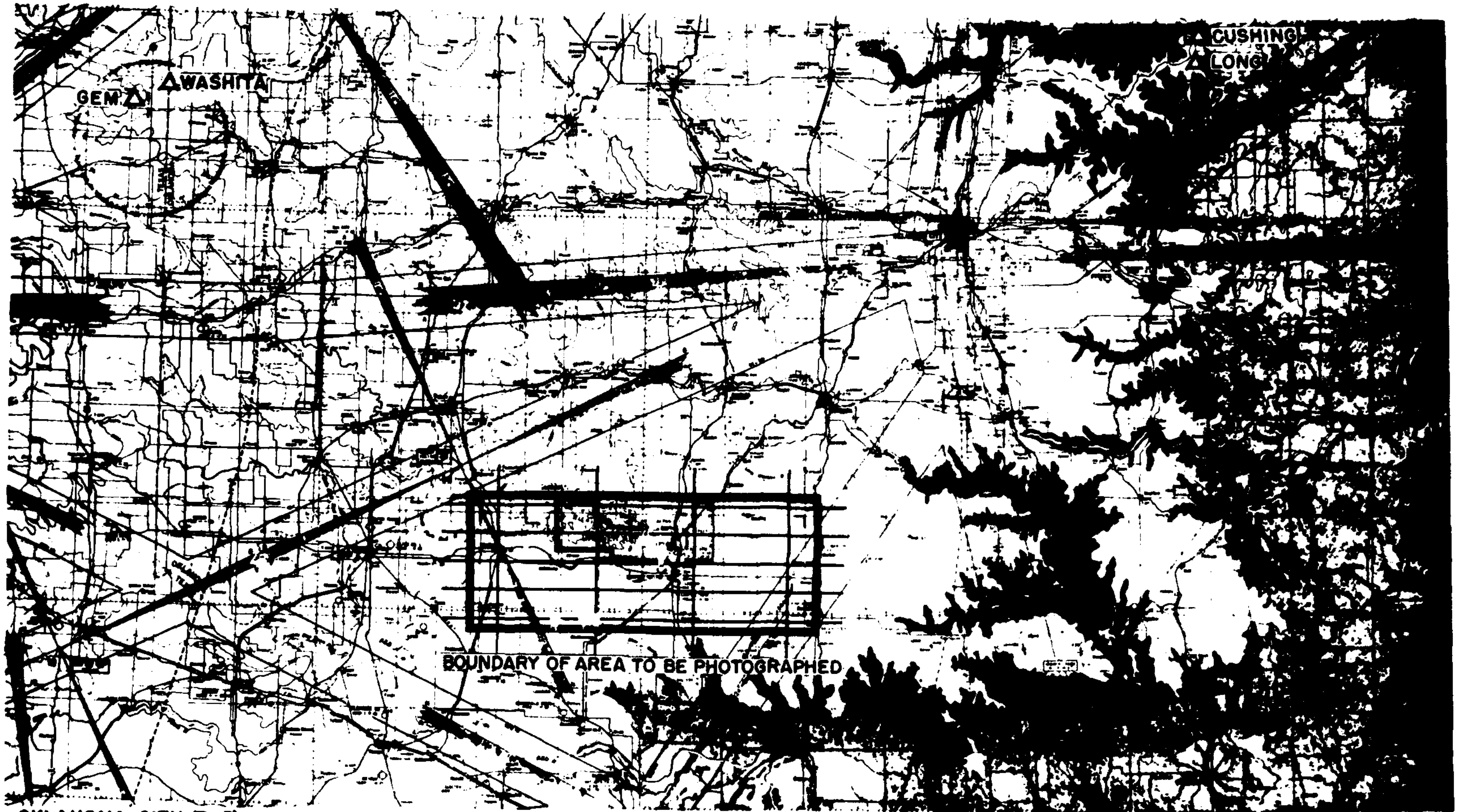
3-12. <u>PROCESSING RECORDING CAMERA FILM</u>. All recording camera film shall be exposed and processed in such a manner as to assure complete legibility of all data.

3-13. <u>RECORDING CAMERA FILM ROLLS</u>. All recording camera rolls of film should be cut and spliced so as to make the recording camera film rolls correspond exactly to the aerial camera film rolls. All splices are to be of a permanent nature.

3-14. <u>INDEXING</u>.

a. The roll numbers assigned to all recording camera film rolls shall be identical to the aerial film roll to which it applies. An identifying suffix shall be added to identify the recorder data such as: 2D, 4A, and 7S, roll 2, distance recorder film; roll 4, altimeter recorder film; and roll 7, oscilloscope recorder film.

b. All recording camera films shall be keyed to the aerial film by having the project name, mission number, aerial film roll number, and aerial film exposure numbers to which it applies lettered onto the clear portion of film at each end adjacent to the end exposure. The exact positions and elevations of the controlling ground antenna stations also shall be lettered onto this clear portion of the distance recording film. The recording camera film shall be spooled with the aerial film to which it applies.



OKLAHOMA CITY (R-5)
SECTIONAL AERONAUTICAL CHART

SPECIFICATION MDSP 428
28 SEPTEMBER 1949

SPECIFICATIONS
FOR
SHORAN CONTROLLED PHOTOGRAPHY

APPENDIX C

TABLES

Table I. Velocity Correction, Values of V_1 Listed for Even 100-foot Increments of H + K

H+K(ft)	000	100	200	300	400	500	600	700	800	900
5,000	-.1867	-.1807	-.1747	-.1687	-.1628	-.1568	-.1509	-.1449	-.1390	-.1331
6,000	-.1272	-.1213	-.1154	-.1096	-.1037	-.0979	-.0920	-.0862	-.0804	-.0746
7,000	-.0688	-.0631	-.0573	-.0516	-.0458	-.0401	-.0344	-.0287	-.0230	-.0173
8,000	-.0117	-.0060	-.0004	+.0053	+.0109	+.0165	+.0221	+.0277	+.0332	+.0388
9,000	.0444	.0499	.0554	.0609	.0665	.0719	.0774	.0829	.0884	.0938
10,000	.0993	.1047	.1101	.1155	.1209	.1263	.1317	.1370	.1424	.1477
11,000	.1530	.1584	.1637	.1609	.1742	.1795	.1848	.1900	.1953	.2005
12,000	.2057	.2109	.2161	.2213	.2265	.2317	.2368	.2420	.2471	.2522
13,000	.2573	.2624	.2675	.2726	.2777	.2827	.2878	.2928	.2979	.3029
14,000	.3079	.3129	.3179	.3228	.3278	.3328	.3377	.3426	.3476	.3525
15,000	.3574	.3623	.3672	.3720	.3769	.3817	.3866	.3914	.3962	.4010
16,000	.4058	.4106	.4154	.4202	.4249	.4297	.4344	.4392	.4439	.4486
17,000	.4533	.4580	.4627	.4673	.4720	.4767	.4813	.4859	.4905	.4952
18,000	.4998	.5044	.5089	.5135	.5181	.5226	.5272	.5317	.5362	.5407
19,000	.5452	.5497	.5542	.5587	.5632	.5676	.5721	.5765	.5809	.5854
20,000	.5898	.5942	.5986	.6029	.6073	.6117	.6160	.6204	.6247	.6290
21,000	.6333	.6377	.6420	.6462	.6505	.6548	.6590	.6633	.6675	.6718
22,000	.6760	.6802	.6844	.6886	.6928	.6970	.7012	.7053	.7095	.7136
23,000	.7177	.7219	.7260	.7301	.7342	.7383	.7424	.7464	.7505	.7545
24,000	.7586	.7626	.7667	.7707	.7747	.7787	.7827	.7867	.7906	.7946
25,000	.7986	.8025	.8065	.8104	.8143	.8182	.8221	.8260	.8299	.8338
26,000	.8377	.8416	.8454	.8493	.8531	.8569	.8607	.8646	.8684	.8722
27,000	.8760	.8797	.8835	.8873	.8910	.8948	.8985	.9023	.9060	.9097
28,000	.9134	.9171	.9208	.9245	.9282	.9318	.9355	.9391	.9428	.9464
29,000	.9501	.9537	.9573	.9609	.9645	.9681	.9717	.9752	.9788	.9824
30,000	.9859	.9895	.9930	.9965	1.0000	1.0035	1.0070	1.0105	1.0140	1.0175
31,000	1.0210	1.0245	1.0279	1.0314	1.0348	1.0382	1.0417	1.0451	1.0485	1.0519
32,000	1.0553	1.0587	1.0621	1.0655	1.0688	1.0722	1.0756	1.0789	1.0822	1.0856
33,000	1.0889	1.0922	1.0955	1.0988	1.1021	1.1054	1.1087	1.1120	1.1153	1.1185
34,000	1.1218	1.1250	1.1283	1.1315	1.1347	1.1379	1.1411	1.1444	1.1476	1.1507
35,000	1.1539	1.1571	1.1603	1.1634	1.1666	1.1698	1.1729	1.1760	1.1792	1.1823
36,000	1.1854	1.1885	1.1916	1.1947	1.1978	1.2009	1.2040	1.2070	1.2101	1.2132
37,000	1.2162	1.2192	1.2223	1.2253	1.2283	1.2314	1.2344	1.2374	1.2404	1.2434
38,000	1.2464	1.2493	1.2523	1.2553	1.2582	1.2612	1.2641	1.2671	1.2700	1.2729
39,000	1.2759	1.2788	1.2817	1.2846	1.2875	1.2904	1.2933	1.2962	1.2990	1.3019
40,000	1.3048	1.3076	1.3105	1.3133	1.3161	1.3190	1.3218	1.3246	1.3274	1.3302

Note: Enter the column at left with H + K to the nearest 1000 feet and move to the right for values to the nearest 100 feet. Interpolate between the 100-foot values for more accurate results.

Table II. Velocity Correction, Values of V_2

M+N (ft) / M−N (ft)	5000	10000	15000	20000	25000	30000	35000	40000
1,000	.0002	.0002	.0002	.0002	.0001	.0001	.0001	.0001
2,000	.0008	.0007	.0007	.0006	.0006	.0005	.0005	.0004
3,000	.0018	.0017	.0015	.0014	.0013	.0012	.0010	.0009
4,000	.0032	.0030	.0027	.0025	.0023	.0021	.0018	.0016
5,000	.0050	.0046	.0043	.0039	.0036	.0032	.0029	.0025
6,000	.0072	.0067	.0062	.0057	.0051	.0046	.0041	.0036
7,000	.0098	.0091	.0084	.0077	.0070	.0063	.0056	.0049
8,000	.0128	.0119	.0110	.0101	.0091	.0082	.0073	.0064
9,000	.0162	.0150	.0139	.0127	.0116	.0104	.0093	.0081
10,000	.0200	.0186	.0171	.0157	.0143	.0129	.0114	.0100
11,000		.0225	.0207	.0190	.0173	.0156	.0138	.0121
12,000		.0267	.0247	.0226	.0206	.0185	.0165	.0144
13,000		.0314	.0290	.0266	.0242	.0217	.0193	.0169
14,000		.0364	.0336	.0308	.0280	.0252	.0224	.0196
15,000		.0418	.0386	.0354	.0322	.0290	.0257	.0225
16,000			.0439	.0402	.0366	.0329	.0293	.0256
17,000			.0495	.0454	.0413	.0372	.0331	.0290
18,000			.0555	.0509	.0463	.0417	.0371	.0325
19,000			.0619	.0567	.0516	.0465	.0413	.0362
20,000			.0686	.0629	.0572	.0515	.0458	.0401
21,000				.0693	.0630	.0568	.0505	.0442
22,000				.0761	.0692	.0623	.0554	.0485
23,000				.0832	.0756	.0681	.0605	.0530
24,000				.0905	.0823	.0741	.0659	.0577
25,000				.0982	.0893	.0804	.0715	.0626
26,000					.0966	.0870	.0774	.0677
27,000					.1042	.0938	.0834	.0730
28,000					.1121	.1009	.0897	.0785
29,000					.1202	.1082	.0962	.0843
30,000					.1286	.1158	.1030	.0902
31,000						.1237	.1100	.0963
32,000						.1318	.1172	.1026
33,000						.1401	.1246	.1091
34,000						.1488	.1323	.1158
35,000						.1576	.1402	.1227

Table III. Velocity Correction, Values of V_3

S (mi) \ H+K (ft)	5000	10000	15000	20000	25000	30000	35000	40000
40	.0001	.0001	.0001	.0001	.0001	.0000	.0000	.0000
50	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
60	.0002	.0002	.0002	.0002	.0002	.0001	.0001	.0001
70	.0004	.0004	.0003	.0003	.0003	.0002	.0002	.0002
80	.0006	.0005	.0005	.0004	.0004	.0003	.0003	.0003
90	.0008	.0008	.0007	.0006	.0006	.0005	.0004	.0004
100	.0012	.0010	.0009	.0008	.0008	.0007	.0006	.0005
110	.0016	.0014	.0013	.0011	.0010	.0009	.0008	.0007
120	.0020	.0018	.0016	.0015	.0013	.0012	.0011	.0010
130	.0026	.0023	.0021	.0019	.0017	.0015	.0014	.0012
140	.0032	.0029	.0026	.0024	.0021	.0019	.0017	.0015
150	.0040	.0036	.0033	.0029	.0026	.0024	.0021	.0019
160	.0049	.0044	.0040	.0036	.0033	.0029	.0026	.0024
170	.0059	.0054	.0048	.0044	.0039	.0035	.0032	.0028
180	.0071	.0064	.0058	.0052	.0047	.0042	.0038	.0034
190	.0084	.0076	.0069	.0062	.0056	.0050	.0045	.0040
200	.0099	.0090	.0081	.0073	.0066	.0059	.0053	.0048
210		.0105	.0095	.0086	.0077	.0069	.0062	.0056
220		.0122	.0110	.0099	.0089	.0080	.0072	.0065
230		.0141	.0127	.0115	.0103	.0093	.0083	.0075
240		.0162	.0146	.0132	.0119	.0107	.0096	.0086
250		.0185	.0167	.0151	.0136	.0122	.0110	.0098
260			.0190	.0172	.0155	.0139	.0125	.0112
270			.0216	.0195	.0176	.0158	.0142	.0128
280			.0244	.0221	.0199	.0179	.0161	.0144
290			.0275	.0249	.0224	.0202	.0181	.0163
300			.0309	.0279	.0252	.0227	.0204	.0183
310				.0313	.0282	.0254	.0229	.0205
320				.0349	.0315	.0284	.0256	.0230
330				.0389	.0352	.0317	.0285	.0256
340				.0433	.0391	.0353	.0317	.0285
350				.0430	.0434	.0392	.0353	.0317
360					.0481	.0434	.0391	.0352
370					.0532	.0480	.0433	.0389
380					.0587	.0530	.0478	.0430
390					.0647	.0585	.0528	.0475
400					.0712	.0644	.0581	.0524

Table IV. Correction for Assumption No. 1

S (mi)	H+K (ft)	H+K (ft)	H+K (ft)	H+K (ft)
160	32,946			
170	27,435			
180	24,797			
190	23,409			
200	22,696			
210	22,398			
220	22,380	46,803		
230	22,563	37,971		
240	22,897	33,913		
250	23,353	31,752		
260	23,907	30,596		
270	24,546	30,021	42,874	
280	25,257	29,836	38,933	
290	26,034	29,926	36,808	
300	26,869	30,221	35,657	
310	27,759	30,677	35,104	
320	28,698	31,263	34,951	40,929
330	29,686	31,957	35,083	39,789
340	30,719	32,743	35,432	39,254
350	31,795	33,610	35,949	39,128
360	32,913	34,549	36,604	39,296
370	34,072	35,553	37,374	39,687
380	35,271	36,617	38,242	40,254
390	36,508	37,737	39,195	40,963
400	37,783	38,908	40,224	41,792
miles $x10^{-3}$	.5	1.5	2.5	3.5

0	1.0	2.0	3.0	4.0

Note: Enter the table for the value of S and observe between which columns the value of H + K lies. The correction can then be found by going down the line between the columns to the value given on the bottom line.